Water Quality Report: 2005

Wachusett Reservoir and Watershed

April 2006

Massachusetts Department of Conservation and Recreation
Division of Water Supply Protection
Office of Watershed Management

ABSTRACT

The Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management (originally known as the Metropolitan District Commission Division of Watershed Management) was established by Chapter 372 of the Acts of 1984. The OWM was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

Water quality sampling and watershed monitoring make up an important part of the overall mission of the new Office of Watershed Management. These activities are carried out by Environmental Quality Section staff at Wachusett Reservoir in West Boylston and at Quabbin Reservoir in Belchertown. This report is a summary of 2005 water quality data from the Wachusett watershed. A report summarizing 2005 water quality data from the Quabbin and Ware River watersheds is also available from the Division.

Acknowledgements:

This plan was prepared by the staff of the Department of Conservation and Recreation Division of Water Supply Protection Office of Watershed Management. Principal authors are Lawrence Pistrang, Environmental Analyst, Wachusett/Sudbury Section and David Worden, Aquatic Biologist, Wachusett/Sudbury Section. Internal review was provided by Pat Austin. Frank Battista, David Worden, David Getman, Kelley Freda, and Lawrence Pistrang collected the samples and were responsible for all field measurements. All bacterial analyses were done at the MWRA Lab in Southboro.

DCR/DWSP/OWM thanks the staff and management of the MWRA Deer Island Lab for preparing and delivering sample bottles and performing all nutrient analyses during the year. They also thank MWRA staff at the Southboro Lab for performing all coliform analyses during the latter half of the year.

All maps were produced by DCR/DWSP/OWM GIS analyst Craig Fitzgerald, using the most recent data.

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WACHUSETT RESERVOIR AND WATERSHED

1.0 INTRODUCTION

The Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management (originally known as the Metropolitan District Commission Division of Watershed Management) was established by Chapter 372 of the Acts of 1984. The OWM was created to manage and maintain a system of watersheds and reservoirs and provide pure water to the Massachusetts Water Resources Authority (MWRA), which in turn supplies drinking water to approximately 2.5 million people in forty-six communities.

The Surface Water Treatment Rule requires filtration of all surface water supplies unless several criteria are met, including the development and implementation of a detailed watershed protection plan. The OWM and the MWRA currently have a joint waiver from the filtration requirement and continue to aggressively manage the watershed in order to maintain this waiver. Water quality sampling and field inspections help identify tributaries with water quality problems, aid in the implementation of the OWM's watershed protection plan, and ensure compliance with state and federal water quality criteria for public drinking water supply sources. Bacterial monitoring of the reservoir and its tributaries provide an indication of sanitary quality and help to protect public health. OWM staff also sample to better understand the responses of the reservoir and its tributaries to a variety of physical, chemical, and biological inputs, and to assess the ecological health of the reservoir and the watershed.

Routine water quality samples were collected from a total of fifty-four stations on thirty tributaries and from three stations on the reservoir, a continuation of the intensified sampling program initiated in 2004. Weekly or twice weekly collection of Wachusett Reservoir plankton was done from the back of the Cosgrove Intake (through March) or from a boat at Station 3417 (Basin North) in order to detect increasing concentrations (blooms) and potential taste and odor problems, and to recommend copper sulfate treatment when necessary. Temperature, pH, dissolved oxygen, and conductivity profiles were taken in conjunction with plankton sampling; quarterly profiles were also measured at two additional reservoir stations. Fecal coliform samples were collected from reservoir surface stations, documenting the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on both birds and bacteria concentrations.

All fecal coliform, conductivity, and associated precipitation data collected are stored in a DCR electronic database (Microsoft EXCEL file Fc_dbase2005.xls) located on the w: drive at the DCR-OWM Water Quality Laboratory in West Boylston. Nutrient data reside on the MWRA LIMS and in DCR electronic files. An electronic file of plankton data is also maintained on site in West Boylston. All data generated during tributary and reservoir water quality testing are discussed by parameter in sections 3.1 – 4.4, and all data are included as appendices to this report.

The Pinecroft Area drainage basin is being investigated to document the positive impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Initial sampling in 1998 established baseline and stormwater nutrient and bacteria levels and profiled water quality within a small urbanized subbasin at the headwaters of Malden Brook prior to sewer construction. [Note: This area previously was considered the headwaters of Gates Brook but drainage patterns have changed following highway construction and an in-depth hydrologic investigation has established that flow enters the Malden Brook subbasin.] Samples were also collected in two similarly sized subbasins with different land uses (agriculture, undeveloped) for comparative purposes. Weekly sampling of the three subbasins has continued through 2005. More than 70% of the homes in the Pinecroft neighborhood are now connected to the municipal sewer and water quality in the subbasin appeared to have improved initially, although a significant decline was observed in 2005. An analysis of the data collected as part of this study is included in this report.

Environmental Quality staff continued to monitor site-specific impacts of development on water quality. Ongoing communications with state and local officials helped ensure implementation of best management practices, remediation of existing problems, and quick notification of imminent threats. Staff attempted to communicate with conservation commission and board of health members on a regular basis to provide technical assistance and to gain advance knowledge of proposed activities. Resumption of regular attendance at conservation commission, planning board, and board of health meetings was discussed and will be in effect during 2006. All investigations and projects were documented as part of a comprehensive filing system.

In an effort to refine the process of threat assessment within the Wachusett watershed, Environmental Quality staff divided the watershed into five sanitary districts with the goal of completing a detailed assessment of one district per year on a five-year rotating basis. Information was gathered on hydrology, natural resources, demographics, land use, historic water quality, and both actual and potential threats for the fourteen subbasins within the Stillwater District. A district overview with detailed information presented in fifteen individual subbasin chapters was prepared, and both general and specific recommendations are being developed. The Stillwater District Environmental Quality Assessment will be published under separate cover in the spring of 2006. Similar data gathering activities will begin at that time for the final group of subbasins (Worcester District) with publication expected by the end of 2006.

Samples were also collected from additional locations to investigate potential water quality problems that were discovered during Environmental Quality Assessment fieldwork and investigations. Water samples were collected during both dry and wet conditions, usually from several locations on a single tributary, to help locate pollution sources. Samples were collected from multiple stations on West Boylston Brook to provide data for a UMASS microbial source tracking project. All data collected are included in this report.

2.0 DESCRIPTION OF WATERSHED MONITORING PROGRAM

Wachusett Environmental Quality staff collected routine water quality samples from fifty-four stations on thirty tributaries and from three stations on the reservoir during 2005. The stations are described below in Table 1 and are located on Figure 1. Additional stations were sampled occasionally to support special studies or potential enforcement actions. Only a small number of samples were analyzed in-house including a total of 144 turbidity samples and 132 plankton samples. Almost 3750 physiochemical measurements (temperature and conductivity) were done in the field. In addition, 3587 samples were collected and delivered to the MWRA laboratory in Southboro for fecal coliform analysis, and sixty-seven samples were collected and shipped to the MWRA Deer Island laboratory for nearly 1200 analyses of nutrients and metals.

Each tributary station was visited weekly throughout the entire year, although samples were not collected at some stations during low flow or no-flow conditions. Temperature and conductivity were measured in the field (except during extreme cold temperatures) using a YSI Model 30 conductivity meter and samples were collected for fecal coliform analysis. All fecal coliform analyses were delivered to the MWRA Southboro Lab for analysis. Samples were collected in March, April, June, July, and November from nine stations and analyzed at the MWRA Deer Island Lab for alkalinity, conductivity, nitrate-nitrogen, nitrite-nitrogen, ammonia, total phosphorus, silica, UV-254, total suspended solids, and total organic carbon. Monthly samples for the same parameters plus metals were collected from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Depth measurements were done at these stations to calculate flow using previously established rating curves. All sample collections and analyses were conducted according to Standard Methods for the Examination of Water and Wastewater 20th Ed. (Table 2).

Precipitation data from NOAA weather stations in Worcester and Fitchburg, from the USGS station on the Stillwater River in Sterling, and from three staff monitored rain gauges in Princeton and West Boylston were collected daily to help interpret water quality data and determine if problems were related to stormwater contamination.

Temperature, dissolved oxygen, pH, and conductivity profiles were usually measured each week at Station 3417 (Basin North) or the Cosgrove Intake in conjunction with routine plankton monitoring, and quarterly at Station 3412 (Basin South) and Thomas Basin. Quarterly samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, silica, dissolved silica, alkalinity, total phosphorus, and UV-254 were collected at the same stations from the epilimnion, metalimnion, and hypolimnion and analyzed at the MWRA Lab at Deer Island.

MWRA personnel collected a regulatory fecal coliform sample from the new John J. Carroll Water Treatment Plant at Walnut Hill in Marlborough five times per week and also collected a weekly sample from the Cosgrove Intake in Clinton to maintain the historical record. Fecal coliform samples were collected once, twice, or three times per month at twenty-three reservoir locations (Figure 2) by DCR Environmental Quality staff to document the relationship between seasonal bacteria variations and roosting populations of gulls and geese on the reservoir as well as the impact of harassment on birds and bacteria concentrations.

TABLE 1 (part one of two)

ROUTINE WACHUSETT SAMPLING STATIONS – 2005

STATION	LOCATION	FREQUENCY
1. Asnebumskit (Mill)	upstream of Mill Street, Holden	W
2. Asnebumskit (Prin)	upstream of Princeton Street, Holden	W
3. Ball Brook	Route 140, Sterling	W
4. Beaman 2	Route 110, W. Boylston (homes)	W
5. Beaman 3	Route 110, W. Boylston (muskrat)	W
6. Beaman 3.5	Route 110, W. Boylston (horses)	W
7. Boylston Brook	Route 70, Boylston	W
8. Chaffins (Malden)	Malden Street, Holden	W
9. Chaffins (Poor Farm)	Newell Road, Holden	W
10. Chaffins (Unionville)	Unionville Pond outlet, Holden	W
11. Chaffins (Wachusett)	Wachusett Street, Holden	W
12. Cook Brook (Wyoming)	Wyoming Street, Holden	W, Q1
13. East Wachusett (140)	Route 140, Sterling	W
14. East Wachusett (31)	Route 31, Princeton	W
15. East Wachusett (Bull)	Bullard Road, Princeton	W
16. French Brook (70)	Route 70, Boylston	W, Q1
17. Gates Brook (1)	Gate 25, W.Boylston	W, Q1
18. Gates Brook (2)	Route 140, W.Boylston	W
19. Gates Brook (3)	Worcester Street, W.Boylston	W
20. Gates Brook (4)	Pierce Street, W.Boylston	W
21. Gates Brook (6)	Lombard Avenue, W.Boylston	W
22. Gates Brook (9)	Woodland Street, W.Boylston	W
23. Hastings Cove Brook	Route 70, Boylston	W
24. Hog Hill Brook	Laurel Street, Holden	W
25. Houghton Brook	Route 140, Sterling	W
26. Jordan Farm Brook	Route 68, Rutland	W
27. Justice Brook	Route 140, Sterling/Princeton line	W
28. Keyes (Gleason)	Gleason Road, Princeton	W
29. Keyes (Hobbs)	Hobbs Road, Princeton	W

W = weekly (bacteria, temperature, conductivity)
Q1 = quarterly+1 (nutrients- March, April, June, July, November)

TABLE 1 (part two of two)

ROUTINE WACHUSETT SAMPLING STATIONS – 2005

STATION	LOCATION	FREQUENCY
30. Keyes (Onion)	behind Quik-Stop, Route 140, Princeton	W
31. Malagasco Brook	West Temple Street, Boylston	W, Q1
32. Malden Brook	Thomas Street, W.Boylston	W, Q1
33. Muddy Brook	Route 140, W.Boylston	W, Q1
34. Oakdale Brook	Waushacum Street, W. Boylston	W
35. Quinapoxet River (CMills)	Canada Mills, Holden	W, M
36. Quinapoxet River (dam)	above circular dam, W.Boylston	W
37. Quinapoxet River (Mill St)	Mill Street, Holden	W
38. Rocky Brook	Beaman Street, Sterling	W
39. Rocky (E Branch)	Justice Hill Road, Sterling	W, Q1
40. Scanlon Brook	Crowley Road, Sterling	W
41. Scarlett Brook	Worcester Street, W.Boylston	W
42. Scarlett (Rt12)	Upstream of Walmart, W. Boylston	W
43. Stillwater (62)	Route 62, Sterling	W
44. Stillwater River (SB)	Muddy Pond Road, Sterling	W, M
45. Swamp 15 Brook	Harris Street, Holden	W
46. Trout Brook	Manning Street, Holden	W
47. Warren Tannery Brook	Quinapoxet Street, Holden	W
48. Waushacum (Conn)	Jewett Road, Sterling	W
49. Waushacum (filter)	above filter beds, Route 12, Sterling	W
50. Waushacum (Fairbanks)	Fairbanks Street, Sterling	W
51. Waushacum (Pr)	Prescott Street, W.Boylston	W
52. Waushacum (WWP)	Gates Road, Sterling (pond outlet)	W
53. West Boylston Brook	Gate 25, W.Boylston	W, Q1
54. Wilder Brook	Wilder Road, Sterling	W
A. 3409 (Reservoir)	Cosgrove Intake	W, Q
B. 3417 (Reservoir)	mid reservoir by Cunningham Ledge	W, Q
C. 3412 (Reservoir)	mid reservoir southwest of narrows	Q
D. TB (Reservoir)	Thomas Basin	Q

W = weekly (bacteria, temperature, conductivity [tributaries], algae and profiles [Cosgrove or 3417])
M = monthly (nutrients and metals)
Q = quarterly (algae, profiles, nutrients [reservoir])
Q1 = quarterly+1 (nutrients- March, April, June, July, November)

Figure 1

Sampling Stations

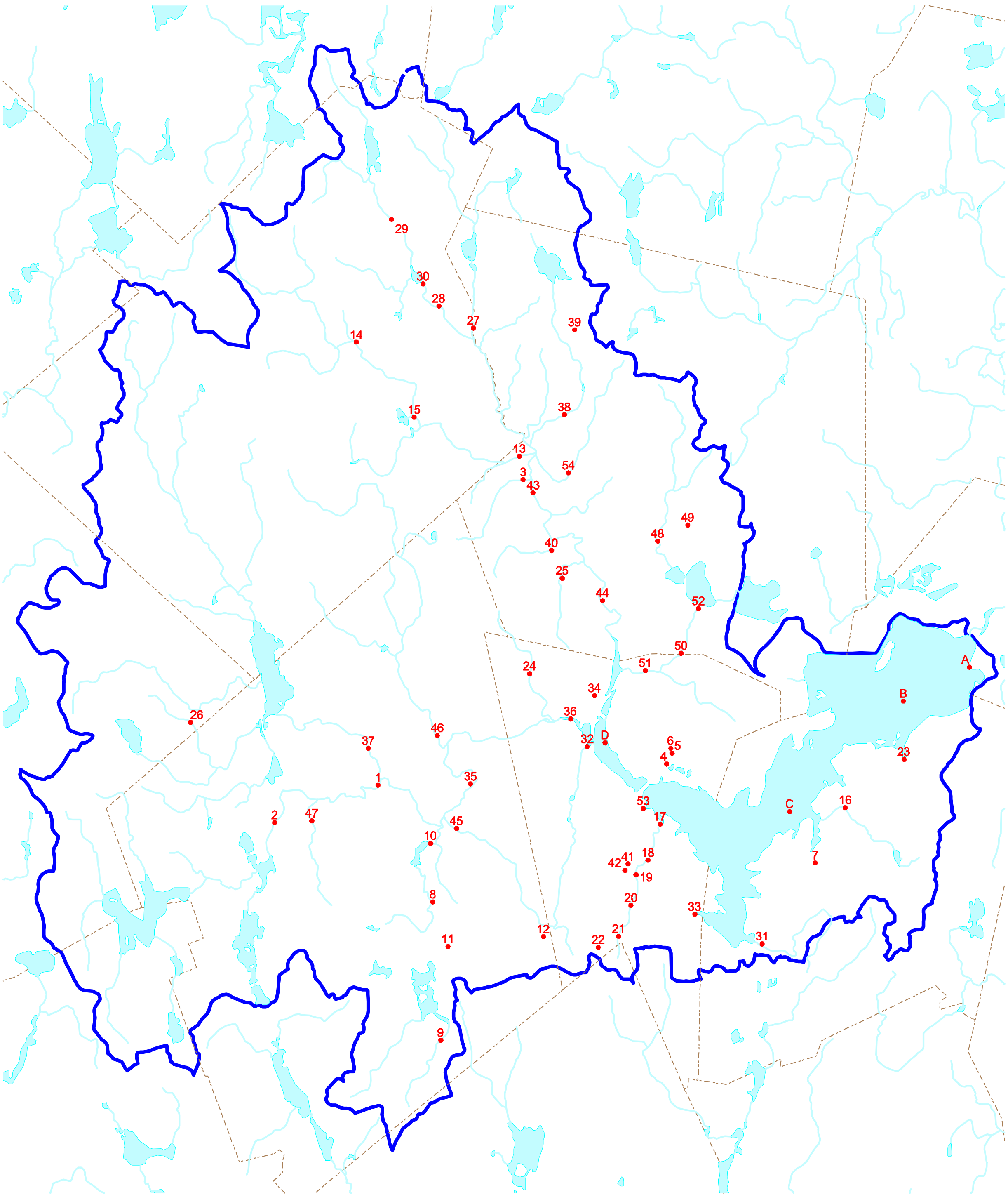


FIGURE 2

RESERVOIR TRANSECT STATIONS

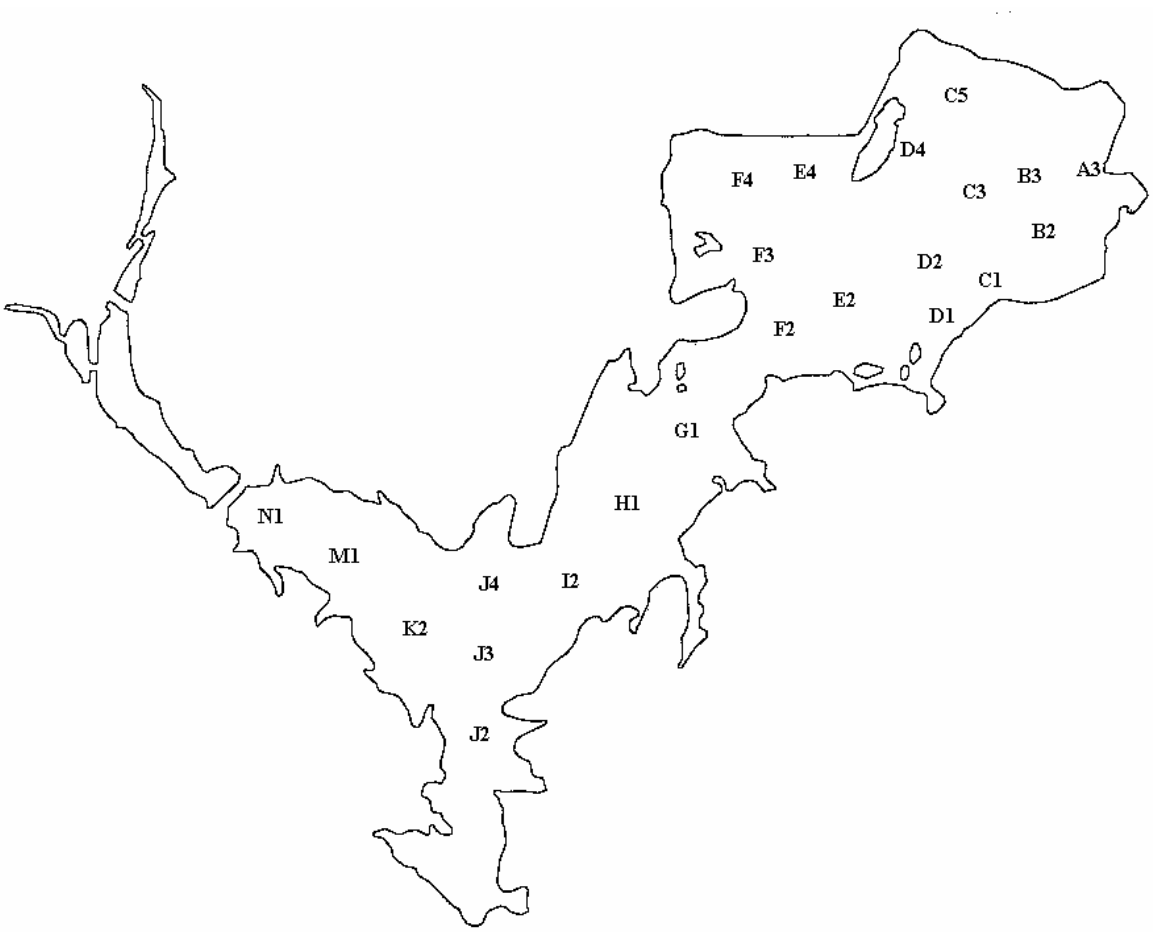


TABLE 2

METHODS USED FOR FIELD AND LABORATORY ANALYSIS WACHUSETT/SOUTHBORO/DEER ISLAND LABORATORIES

PARAMETER	STANDARD METHOD
pH	Hydrolab Surveyor III
Conductivity	YSI Model 30 meter Hydrolab Surveyor III
Temperature	Hydrolab Surveyor III YSI Model 30 meter
Dissolved Oxygen	Hydrolab Surveyor III
Total Phosphorus	EPA 365.1
Ammonia-Nitrogen	EPA 349.0
Nitrate-Nitrogen	EPA 353.4
Total Kjeldahl-Ntrogen	EPA 351.2
Silica	EPA 200.7
Dissolved Silica	EPA 200.7
UV254	SM 5910A SM5910B
Alkalinity	EPA 310.1 SM 2320B
Fecal Coliform	SM 9222 D
Plankton	SM 10200 F

SM = Standard Methods for the Examination of Water and Wastewater - 20th edition, 1999

3.0 RESULTS OF TRIBUTARY MONITORING PROGRAM

3.1 BACTERIA

Fecal coliform concentrations were measured as an indicator of sanitary quality. Coliform density has been established as a significant measure of the degree of pollution and has been used as a basis of standards for bacteriological quality of water supplies for some time. Fecal coliform are defined in Standard Methods for the Examination of Water and Wastewater - 20th edition (1999) as a subset of total coliform bacteria that produce blue colonies on M-FC media when incubated for 24 hours at 44.5° C. Fecal coliform bacteria are found within the digestive system of warm-blooded animals and are almost always present in water containing pathogens. Fecal coliform are relatively easy to isolate in a laboratory, and direct counts can be made using membrane filtration. The presence of coliform bacteria in water suggests that there may be disease-causing agents present as well.

Fecal coliform concentrations were measured weekly at all tributary stations. The Massachusetts Class A surface water quality standards established at 314 CMR 4.00 state that "fecal coliform bacteria shall not exceed an arithmetic mean of 20 colonies per 100 mL in any representative set of samples, nor shall more than 10% of the samples exceed 100 colonies per 100 mL". Using a yearly arithmetic mean, the standard of 20 colonies per 100 mL was exceeded at forty-nine of fifty-four tributary stations (91%). Only Ball Brook, East Wachusett Brook (31), Justice Brook, and Keyes Brook (stations at Gleason Road and the Onion Patch) had an annual mean value less than the standard. Sixteen stations had less than 10% of the samples collected containing more than 100 colonies per 100 mL, however, which seems to suggest that mean values were once again elevated by a small percentage of high measurements during 2005. One or two high values can markedly elevate the annual mean of a relatively small data set, and fecal coliform values often increase by several orders of magnitude following storm events or during periods of high groundwater. An alternate way of looking at summary data may give a better representation of actual conditions in these tributaries throughout the year. The use of median values to represent water quality has been used for many years by Environmental Quality staff. Table 3 includes both annual mean and annual median values for fecal coliform data in the tributaries.

Supporting precipitation data from the NOAA weather stations in Worcester and Fitchburg, from the USGS station on the Stillwater River in Sterling, and from three staff monitored rain gauges in Princeton and West Boylston were used to interpret fecal coliform data by helping segregate water quality samples impacted by storm events from those more representative of baseline conditions. Storm events continue to have a significant impact on fecal coliform concentrations in most tributaries. A storm event was defined as precipitation of greater than 0.2 inches that occurred within forty-eight hours of sampling, although the majority of the impacts were the result of rainfall within twenty-four hours of sampling. The importance of precipitation events is illustrated in Tables 4 and 5. The effect of storm events on both mean and median fecal coliform is addressed, as well as the impact of rainfall as causal agent for the intermittent high concentrations observed in many of the tributaries.

TABLE 3 (part one of two)

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN (2005)	MEDIAN (2004)	SAMPLES
Asnebumskit (Mill)	1590	<10	125	23	30	42
Asnebumskit (Prin)	9300	<10	566	60	80	51
Ball Brook	120	<10	20	10	<10	38
Beaman 2	2600	<10	159	30	90	44
Beaman 3	7800	<10	360	30	70	39
Beaman 3.5	>2000	<10	244	40	175	37
Boylston Brook	1700	<10	104	10	25	39
Chaffins (Malden)	>2000	<10	200	20	20	50
Chaffins (Poor Farm)	>3000	<10	189	20	10	50
Chaffins (Unionville)	530	<10	31	<10	<10	50
Chaffins (Wachusett)	>2000	<10	196	20	25	50
Cook Brook (Wyoming)	4400	<10	422	**70**	30	51
East Wachusett (140)	280	<10	49	25	20	48
East Wachusett (31)	150	<10	19	<10	<10	49
East Wachusett (Bull)	150	<10	21	10	10	49
French Brook (70)	380	<10	38	10	15	51
Gates Brook (1)	15000	<10	359	20	25	53
Gates Brook (2)	11000	<10	572	60	30	51
Gates Brook (3)	13000	<10	358	20*	30	51
Gates Brook (4)	20000	<10	536	40	50	50
Gates Brook (6)	19000	<10	549	70	50	51
Gates Brook (9)	1800	<10	110	30	55	51
Hastings Cove Brook	570	<10	42	10	<10	41
Hog Hill Brook	1320	<10	80	10*	10*	43
Houghton Brook	4300	<10	151	15	10	50
Jordan Farm Brook	14600	<10	1116	10	<10	37
Justice Brook	120	<10	14	<10	<10	50

*below historic levels

TABLE 3 (part two of two)

FECAL COLIFORM - TRIBUTARIES
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN (2005)	MEDIAN (2004)	SAMPLES
Keyes (Gleason)	100	<10	14	<10*	<10*	49
Keyes (Hobbs)	170	<10	30	10	10	50
Keyes (Onion)	270	<10	18	<10	<10	50
Malagasco Brook	20000	<10	453	20	20	52
Malden Brook	2200	<10	84	10*	30	54
Muddy Brook	420	<10	41	10	20	52
Oakdale Brook	>2000	<10	184	40	50	51
Quinapoxet River (CMills)	1600	<10	95	30*	50	105
Quinapoxet River (dam)	680	<10	80	20	20	47
Quinapoxet River (Mill St)	440	<10	28	10	10	50
Rocky Brook	280	<10	37	15	10	50
Rocky (E Branch)	330	<10	30	<10	<10	39
Scanlon Brook	1100	<10	81	<10	<10	46
Scarlett Brook	>2000	<10	245	30	20	52
Scarlett (Rt12)	3200	<10	383	30	10	42
Stillwater (62)	320	<10	57	30	20	50
Stillwater River (SB)	810	<10	83	30	40	104
Swamp 15 Brook	1290	<10	116	30	10	50
Trout Brook	770	<10	46	10	<10	50
Warren Tannery Brook	1900	<10	94	10*	15	50
Waushacum (Conn)	1430	<10	79	20	<10	41
Waushacum (filter)	3700	<10	314	10	20	38
Waushacum (Fairbanks)	>2000	<10	140	20	20	51
Waushacum (Pr)	740	<10	51	20	10	50
Waushacum (WWP)	>2000	<10	83	<10	<10	51
West Boylston Brook	7800	<10	316	60	50	54
Wilder Brook	>2000	<10	187	30	25	26

*below historic levels

Arithmetic mean fecal coliform concentrations have been used as part of the Massachusetts Class A surface water quality standards for some time, but there are limitations with this parameter as described earlier and revisions to the standards are under consideration by the Massachusetts Department of Environmental Protection. Annual median has been used by DCR Environmental Quality staff for many years as a better measure to represent overall water quality. Most annual median concentrations recorded in 2005 were comparable to those measured during 2004 and in previous years. Six stations (Gates 3, Hog Hill, Keyes at Gleason, Malden, Warren Tannery, and the Quinapoxet River at Canada Mills) did record their lowest ever annual median, and all three stations on Beaman Pond Brook continue to show significant improvement (the latter due to the removal of horses from a property adjacent to the stream). Two stations (Cook and Gates 2) showed declining water quality and the former recorded its highest ever median coliform concentration, disturbing in light of the fact that many of the homes in the surrounding subbasin have been connected to the new municipal sewer. The remaining forty-three sampling stations all had median fecal coliform concentrations that were not unusually high or low and did not show any clear historical trends.

Jordan Farm Brook had the highest annual mean concentration of fecal coliform, but this was the result of eight very high values associated with rain events. Thirty-two stations had higher annual median concentrations. Asnebumskit (Princeton Street) had the second highest annual mean concentration, and also had the third highest annual median concentration. Storm events were not the only cause of elevated fecal coliform concentrations at this station, with fourteen very high values (>100 cfu/mL) recorded on days not associated with rainfall. The source of contamination remains unclear. Stations on Gates Brook and the station on Cook Brook were among the ten worst when ranked by either mean or median values, and persistent sources of contamination obviously still exist. Malagasco Brook, on the other hand, had the fifth worst water quality when ranked using annual means, but was better than twenty stations when ranked by annual median. The annual mean at this station was greatly influenced by a single value of 20,000 cfu/mL recorded following a summer rain event.

Mean values at almost every station were strongly impacted by rainfall events as illustrated in Table 4 on the following pages. Annual mean values were significantly reduced (>20%) in most tributaries when samples collected during or within forty-eight hours of storm events of 0.2 inches or more were excluded. This suggests that these sites were strongly impacted by stormwater pollution. Exclusion of storm samples from statistical analysis resulted in significant improvements at all but five stations. Water quality at Keyes Brook (Onion Patch) and at Rocky Brook (East Branch) is quite good during both wet and dry conditions, and it appears that storm events do not have a significant impact. Stormwater effects at Waushacum (WWP) and at Houghton Brook are likely mitigated by the ponds immediately upstream of the sampling locations, and in the latter case a continual source of contamination (beaver) was observed. Water quality in Scarlett Brook (Route 12) exhibited intermittent and erratic declines, and it appears that there may be a source or sources of contamination unrelated to stormwater impacts. An investigation of a commercial facility adjacent to this station is currently underway.

The obvious impact of storm events on annual mean is the primary reason to seek an alternative measure of water quality when attempting to assess long term trends. Other options include looking at selected subsets of water quality data that segregate results by rain amounts, season, or flow.

TABLE 4 (part one of two)

MEAN AND MEDIAN FECAL COLIFORM – EFFECT OF >0.2" RAINFALL (colonies/100 mL)

STATION	MEAN all samples	MEAN no storm samples	MEDIAN all samples	MEDIAN no storm samples
Asnebumskit (Mill)	125	36	23	10
Asnebumskit (Prin)	566	376	60	35
Ball Brook	20	12	10	<10
Beaman 2	159	24	30	10
Beaman 3	360	46	30	20
Beaman 3.5	244	48	40	30
Boylston Brook	104	49	10	<10
Chaffins (Malden)	200	16	20	10
Chaffins (Poor Farm)	189	55	20	10
Chaffins (Unionville)	31	11	<10	<10*
Chaffins (Wachusett)	196	34	20	20*
Cook Brook (Wyoming)	422	63	**70**	55
East Wachusett (140)	49	36	25	15
East Wachusett (31)	19	11	<10	<10*
East Wachusett (Bull)	21	15	10	<10
French Brook (70)	38	13	10	<10
Gates Brook (1)	359	43	20	10
Gates Brook (2)	572	181	60	35
Gates Brook (3)	358	34	20	20*
Gates Brook (4)	536	68	40	30
Gates Brook (6)	549	151	70	60
Gates Brook (9)	110	42	30	10
Hastings Cove Brook	42	26	10	<10
Hog Hill Brook	80	18	10	<10
Houghton Brook	151	194*	15	<10
Jordan Farm Brook	1116	37	10	10*
Justice Brook	14	11	<10	<10*

*less than 20% improvement

TABLE 4 (part two of two)

MEAN AND MEDIAN FECAL COLIFORM – EFFECT OF >0.2" RAINFALL
(colonies/100 mL)

STATION	MEAN all samples	MEAN no storm samples	MEDIAN all samples	MEDIAN no storm samples
Keyes (Gleason)	14	11	<10	<10*
Keyes (Hobbs)	30	23	10	<10
Keyes (Onion)	18	16*	<10	<10*
Malagasco Brook	453	43	20	10
Malden Brook	84	30	10	<10
Muddy Brook	41	32	10	10*
Oakdale Brook	184	53	40	25
Quinapoxet River (CMills)	95	38	30	15
Quinapoxet River (dam)	80	26	20	10
Quinapoxet River (Mill St)	28	10	10	<10
Rocky Brook	37	23	15	10
Rocky (E Branch)	30	27*	<10	<10*
Scanlon Brook	81	30	<10	<10*
Scarlett Brook	245	175	30	30*
Scarlett (Rt12)	383	386*	30	20
Stillwater (62)	57	46	30	20
Stillwater River (SB)	83	47	30	10
Swamp 15 Brook	116	32	30	10
Trout Brook	46	19	10	<10
Warren Tannery Brook	94	21	10	10*
Waushacum (Conn)	79	33	20	20*
Waushacum (filter)	314	92	10	10*
Waushacum (Fairbanks)	140	82	20	20*
Waushacum (Pr)	51	25	20	20*
Waushacum (WWP)	83	110*	<10	<10*
West Boylston Brook	316	130	60	60*
Wilder Brook	187	68	30	20

*less than 20% improvement

Median fecal coliform concentrations were less affected by rainfall (Table 4). Annual median values did not improve as dramatically as annual mean values when samples collected during or within forty-eight hours of storm events of 0.2 inches or more were excluded, but at least some improvement was noted at all but nineteen of the fifty-four stations. Many of the stations that did not show any improvement had low annual medians even with storm impacted samples included. The exceptions were Scarlett Brook and West Boylston Brook. Water quality at the Scarlett Brook sampling station reflects conditions at the upstream Scarlett Brook (Route 12) station. Intermittent and erratic declines in water quality at this location appear unrelated to stormwater impacts. Water quality in West Boylston Brook seems to be worst during the winter which is contrary to almost all other locations. It is unrelated to storm events and may be linked to wild animals using the culverts for shelters. An investigation by UMASS and OWM staff using microbial source tracking is currently underway.

Median values help temper the impact of rare storm events on annual statistics, so exclusion of storm-related samples would not normally be expected to significantly impact annual median fecal coliform concentrations. There were an unusually high number of samples (35%) collected during or after storm events in 2005, however, which explains the noticeable effect of storm events on median values during this year.

An examination of the relationship between storm events and the percentage of samples that exceed 100 cfu/100mL (extreme high concentrations referred to as "spikes") showed significant improvement in water quality when storm-related samples were excluded, but not at every station (Table 5). No improvement was noted at Keyes Brook (Gleason) or at Rocky Brook (East Branch), two stations with excellent water quality. None was seen at Houghton Brook or Waushacum Brook (WWP) where upstream ponds reduce the impact of storm events. Seventeen percent of all samples collected during 2005 exceeded 100 cfu/100mL. Thirty-one percent of storm-related samples and ten percent of 'dry' samples exceeded the standard. Many of the fecal coliform "spikes" are the obvious result of storm events, but there remains a number of unexplained intermittent occurrences at most stations as well as a few stations where fecal coliform concentrations in excess of 100 cfu/100mL is the norm rather than the exception.

The percentage of samples exceeding 20 cfu/100mL declined when storm-related samples were excluded, but not as much as expected and not at every station (Table 5). The percentage from Muddy Brook was unchanged when storm samples were removed, and there were two stations where removal of storm-related samples actually increased the percentage of samples exceeding the standard. Both Scarlett and West Boylston Brooks were identified earlier as locations where contamination appeared unrelated to storm events. The majority of the improvements to water quality are related to the reduction in the number of samples with extremely high concentrations that are associated with storm events. The number of samples with concentrations that are higher than 20 cfu/100mL but do not exceed 100 cfu/100mL remains fairly constant, with twenty-five percent of all samples and twenty-four percent of 'dry' samples meeting that criteria.

Table 5 identifies a number of tributaries where poor water quality is directly linked to storm events. Ball, Beaman 2, Chaffins (Malden), East Wachusett (31), East Wachusett (Bullard), Hog Hill, French, Justice, Quinapoxet (Mill St), Warren Tannery, and Waushacum (Prescott) exceeded 100 cfu/100mL only during or after rain events.

TABLE 5 (part one of two)

FECAL COLIFORM SPIKES – EFFECT OF >0.2" RAINFALL

STATION	% > 20cfu all samples	% > 20cfu no storm samples	% > 100cfu all samples	% > 100cfu no storm samples
Asnebumskit (Mill)	50	37	24	15
Asnebumskit (Prin)	59	53	49	44
Ball Brook	24	13	3	0
Beaman 2	52	39	16	0
Beaman 3	59	44	28	8
Beaman 3.5	62	58	27	13
Boylston Brook	41	28	10	7
Chaffins (Malden)	38	19	18	0
Chaffins (Poor Farm)	46	42	30	19
Chaffins (Unionville)	24	6	6	3
Chaffins (Wachusett)	46	35	22	10
Cook Brook (Wyoming)	69	56	35	18
East Wachusett (140)	50	43	13	7
East Wachusett (31)	18	6	2	0
East Wachusett (Bull)	24	19	4	0
French Brook (70)	27	12	10	0
Gates Brook (1)	38	28	15	6
Gates Brook (2)	61	55	27	18
Gates Brook (3)	43	32	18	8
Gates Brook (4)	64	58	30	19
Gates Brook (6)	67	59	39	32
Gates Brook (9)	53	41	18	11
Hastings Cove Brook	29	21	10	7
Hog Hill Brook	37	19	14	0
Houghton Brook	44	38	24	25
Jordan Farm Brook	41	22	24	4
Justice Brook	10	9	2	0

TABLE 5 (part two of two)

FECAL COLIFORM SPIKES – EFFECT OF >0.2" RAINFALL

STATION	% > 20cfu all samples	% > 20cfu no storm samples	% > 100cfu all samples	% > 100cfu no storm samples
Keyes (Gleason)	14	13	0	0
Keyes (Hobbs)	34	28	4	3
Keyes (Onion)	12	6	4	3
Malagasco Brook	44	37	17	9
Malden Brook	33	19	13	5
Muddy Brook	40	40	10	9
Oakdale Brook	61	50	27	18
Quinapoxet River (CMills)	52	41	19	10
Quinapoxet River (dam)	38	24	19	7
Quinapoxet River (Mill St)	24	6	4	0
Rocky Brook	38	28	8	3
Rocky (E Branch)	21	20	8	8
Scanlon Brook	28	21	13	7
Scarlett Brook	56	57	29	20
Scarlett (Rt12)	55	48	24	15
Stillwater (62)	54	47	16	16
Stillwater River (SB)	52	43	19	11
Swamp 15 Brook	52	45	20	6
Trout Brook	30	13	8	3
Warren Tannery Brook	42	26	12	0
Waushacum (Conn)	49	44	12	4
Waushacum (filter)	45	30	26	17
Waushacum (Fairbanks)	47	41	22	18
Waushacum (Pr)	44	36	8	0
Waushacum (WWP)	18	15	12	12
West Boylston Brook	74	81	30	27
Wilder Brook	50	44	23	19

A matrix was developed for each sampling station that illustrates the relationship between rain events, the timing of these events, and fecal coliform concentrations. These are included with the weekly data in the appendix, and a sample is presented below.

fecal coliform concentration (cfu/100mL)	**0-20**	**21-99**	**100+**
dry (no rainfall w/i 48 hours)	26	10	0
0.2 + " rain w/i 6 hours	0	2	2
0.2 + " rain w/i 6 and w/i 24 hours	1	0	1
0.2 + " rain w/i 24 hours	0	3	3
0.2 + " rain w/i 24 and w/i 48 hours	0	0	1
0.2 + " rain w/i 48 hours	1	0	0

Results from 2005 clearly show the negative impacts of storm events on many tributaries, but additional sampling remains necessary to refine our understanding of these impacts. In some of the streams (especially those with smaller subbasins) the negative impacts appear to occur immediately after an event, with high concentrations of fecal coliform measured within a few hours. In others (larger rivers) the impacts are often delayed, with the highest concentrations usually observed twenty-four hours or more after the storm event. The duration of negative impacts also appears to be variable, and seasonal effects also have a significant impact on water quality changes. Stormwater sampling will continue during 2006 to gather additional data from both large and small tributaries, and samples will be collected for several days following storms to document temporal changes in fecal coliform concentrations. A significant effort will be made to interpret information to help provide additional information on the timing and duration of storm-related impacts.

A large amount of water quality data with associated rainfall totals has already been compiled and some initial interpretation of seasonal effects has been attempted. Data from 2004 and 2005 were examined because the same sampling stations were monitored weekly during both years. Results from the two years were found to be very similar (Table 6). It is clear that water quality during the winter (January through March) is quite good, with more than 85% of all samples (dry or wet) containing less than 20 cfu/100mL. Water quality declines in the spring (April – June) with only half of the samples collected meeting the standard, and continues to decline during the summer months (July – September). Only about a third of the dry weather samples contain less than 20 cfu/100mL, and less than twenty percent of wet weather samples meet the standard. An improvement in water quality was noted during the fall of both years, but it was much more pronounced in 2004 than in 2005. Seventy-five percent of the samples from the fall of 2004 met the water quality standard, but only fifty-eight percent did the same in 2005. This was not necessarily indicative of an overall water quality decline but instead reflects the unusually large number of significant storm events sampled during the fall of 2005. Water quality of dry samples in the fall of 2004 and 2005 was similar. An obvious difference in fall wet weather water quality, with considerably worse conditions exhibited in 2005, is illustrated in Table 6.

Water quality does not follow the same seasonal pattern in every stream. Most tributaries exhibit their poorest water quality during the summer months, but a number of stations had significantly worse water quality during the spring or the fall (Table 7). In most cases these were streams with good overall water quality that were primarily impacted by storm events.

TABLE 6

FECAL COLIFORM – SEASONAL PATTERNS (DRY AND WET) IN 2004-2005

	WINTER-05	SPRING-05	SUMMER-05	FALL-05
total samples collected	657	728	618	659
% samples < 20 col/100mL (‘clean’)	85	56	29	58
% samples > 20 col/100mL	10	29	37	26
% samples > 100 col/100mL	5	15	34	16

	WINTER-04	SPRING-04	SUMMER-04	FALL-04
total samples collected	689	719	640	602
% samples < 20 col/100mL (‘clean’)	86	44	27	75
% samples > 20 col/100mL	11	32	35	18
% samples > 100 col/100mL	2	24	38	7

	WINTER-05	SPRING-05	SUMMER-05	FALL-05
total dry samples collected	490	447	383	422
% samples < 20 col/100mL (‘clean’)	88	61	36	73
% samples > 20 col/100mL	8	31	40	21
% samples > 100 col/100mL	4	9	24	6

	WINTER-04	SPRING-04	SUMMER-04	FALL-04
total dry samples collected	675	417	417	446
% samples < 20 col/100mL (‘clean’)	86	49	32	79
% samples > 20 col/100mL	12	34	43	16
% samples > 100 col/100mL	2	18	25	5

	WINTER-05	SPRING-05	SUMMER-05	FALL-05
Total wet samples collected	167	281	235	237
% samples < 20 col/100mL (‘clean’)	77	48	18	30
% samples > 20 col/100mL	14	26	33	35
% samples > 100 col/100mL	9	26	49	35

	WINTER-04	SPRING-04	SUMMER-04	FALL-04
total wet samples collected	14	302	223	156
% samples < 20 col/100mL (‘clean’)	93	35	12	64
% samples > 20 col/100mL	7	33	26	24
% samples > 100 col/100mL	0	32	62	12

Some tributaries had fewer samples with elevated concentrations in the summer due in part to a reduced overall number of summer samples caused by low flow conditions. Stations on Scarlett Brook exhibited a decline in water quality in the fall which has yet to be explained.

TABLE 7 (part one of two)

SEASONAL DIFFERENCES - HIGH FECAL COLIFORM

STATION	%>100 winter	%>100 spring	%>100 summer	%>100 fall	%>100 TOTAL
Asnebumskit (Mill)	25	31	31	8	24
Asnebumskit (Prin)	8	54	100	25	48
Ball Brook	0	8	0	0	3
Beaman 2	0	8	43	27	16
Beaman 3	18	8	75	45	28
Beaman 3.5	9	15	100	45	27
Boylston Brook	9	0	50	9	10
Chaffins (Malden)	8	23	23	17	18
Chaffins (Poor Farm)	0	38	54	25	30
Chaffins (Unionville)	0	15	8	0	6
Chaffins (Wachusett)	0	23	46	17	22
Cook Brook (Wyoming)	38	15	54	33	35
East Wachusett (140)	0	8	23	17	13
East Wachusett (31)	0	8	0	0	2
East Wachusett (Bull)	0	8	8	0	4
French Brook (70)	0	8	15	18	10
Gates Brook (1)	14	8	15	25	15
Gates Brook (2)	8	23	54	25	27
Gates Brook (3)	0	8	31	33	18
Gates Brook (4)	15	23	62	18	30
Gates Brook (6)	0	38	92	25	39
Gates Brook (9)	0	15	38	17	18
Hastings Cove Brook	0	0	25	8	10
Hog Hill Brook	0	23	14	18	14
Houghton Brook	0	31	62	0	24
Jordan Farm Brook	22	0	50	45	24
Justice Brook	0	8	0	0	2

TABLE 7 (part two of two)

SEASONAL DIFFERENCES - HIGH FECAL COLIFORM

STATION	%>100 winter	%>100 spring	%>100 summer	%>100 fall	%>100 TOTAL
Keyes (Gleason)	0	0	0	0	0
Keyes (Hobbs)	8	0	8	0	4
Keyes (Onion)	0	0	0	17	4
Malagasco Brook	0	7	46	17	17
Malden Brook	7	0	31	17	13
Muddy Brook	0	15	8	17	10
Oakdale Brook	8	15	69	17	27
Quinapoxet River (CMills)	0	19	42	16	19
Quinapoxet River (dam)	0	31	31	17	21
Quinapoxet River (Mill St)	0	0	15	0	4
Rocky Brook	0	15	0	17	8
Rocky (E Branch)	0	8	0	17	8
Scanlon Brook	0	8	50	0	13
Scarlett Brook	15	15	38	46	29
Scarlett (Rt12)	8	8	40	55	24
Stillwater (62)	0	31	31	8	18
Stillwater River (SB)	4	16	46	12	19
Swamp 15 Brook	0	31	31	17	20
Trout Brook	0	15	8	8	8
Warren Tannery Brook	8	23	15	0	12
Waushacum (Conn)	0	0	71	0	12
Waushacum (filter)	0	46	40	18	26
Waushacum (Fairbanks)	0	15	62	8	22
Waushacum (Pr)	0	8	8	17	8
Waushacum (WWP)	0	8	31	8	12
West Boylston Brook	40	8	38	33	30
Wilder Brook	0	42	100	0	23

Multiple sampling stations on Gates Brook have been utilized for many years to try and locate sources of fecal contamination. Gates Brook was historically one of the most contaminated tributaries in the watershed, although water quality has improved as an increasing number of homes are connected to the new municipal sewers. Annual median fecal coliform concentration at Gates 3 during 2005 was the lowest ever recorded, and all stations except Gates 2 and Gates 6 had annual median concentrations below the average of values measured over the past ten years. A total of 1059 homes, apartments, and businesses have been connected to the West Boylston sewer system in the past seven years, 557 of those within the Gates Brook subbasin. Although nearly seventy percent of all homes in the Gates Brook subbasin are now connected, water quality in Gates Brook is still poor during both wet and dry weather. Specific sources of contamination remain largely undetected and no clear patterns have emerged. Stations close to the tributary sources were more contaminated than stations close to the reservoir during 2004, but in 2005 Gates 2 and Gates 6 had the highest annual mean and highest annual median values, and both had a high percentage of samples exceeding 20 colonies and 100 colonies per 100mL (Table 8). Water quality at Gates 4 was only marginally better, but improved water quality was noted at Gates 9 and Gates 3. The station closest to the reservoir (Gates 1) continues to have the best water quality. If influence of storm events is removed from the statistical analysis (eliminating all samples collected within 48 hours of a storm event of 0.2" or greater) there is very little change; Gates 2, Gates 4, and Gates 6 are still the most contaminated stations during dry weather and Gates 1 consistently has the best water quality. Additional analysis of specific sewer connections and their relationship to water quality at individual stations is ongoing.

TABLE 8

FECAL COLIFORM – GATES BROOK STATIONS
(colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN	%>20	%>100
Gates 1	15000	<10	359	20	38	15
Gates 2	11000	<10	572	60	61	27
Gates 3	13000	<10	358	20*	43	18
Gates 4	20000	<10	536	40	64	30
Gates 6	19000	<10	549	70	67	39
Gates 9	1800	<10	110	30	53	18

Samples were collected from three stations on Beaman Pond Brook to continue an investigation of water quality problems that were discovered during Environmental Quality Assessment fieldwork and investigations. Water samples were collected during both dry and wet conditions. Data from this tributary were collected from Station #2 (downstream of houses), Station #3 (downstream of pond), and Station #3½ (downstream of horses) and are summarized in Table 9. Data from 2003 and 2004 highlighted poor water quality at the station downstream of a property where horses were stabled during portions of the year, with annual median fecal coliform concentrations at the three stations of 70 – 175 cfu/100mL. No best management practices were being used by the owners to keep manure out of the brook. Data from 2005 show dramatic water quality improvements which reflect the removal of the horses from the site.

TABLE 9

FECAL COLIFORM – BEAMAN POND BROOK STATIONS (colonies/100 mL)

STATION	MAX	MIN	MEAN	MEDIAN	%>20	%>100
Beaman Pond #2	2600	<10	159	30	52	16
Beaman Pond #3	7800	<10	360	30	59	28
Beaman Pond #3½	>2000	<10	244	40	62	27

Fecal coliform samples have been collected from stations on Cook Brook for the past eight years to evaluate the impacts of sewering on water quality. Cook Brook flows through the Pinecroft neighborhood of West Boylston and Holden, an area known for numerous problems with outdated or inadequate septic systems. A decision was made in the late 1990s to replace the septic systems with a municipal sewer system. Fecal coliform data were collected in 1998 prior to sewer construction, and weekly data collection has continued since then. A large number of homes have been connected to sewers in this neighborhood during the past seven years. Initial results seemed to show improvements to water quality as a result of the new sewers, with a drop in both annual median fecal coliform concentration and the percentage of samples that exceed 20 colonies per 100mL, but water quality declined significantly in 2005 and the annual median was the highest ever. The cause of this decline is currently under investigation .

Additional samples are collected from tributaries when fecal coliform concentrations are abnormally high and there is no obvious cause. A sample collected from West Boylston Brook on March 8th, 2004 contained more than 2500 fecal coliform per 100mL, so samples were collected from the same station and from two upstream locations the following day. The sample collected at Route 12 was found to contain high amounts of fecal coliform, but no source was identified and concentrations were back to normal the following week. Elevated concentrations were noted again at the same station in January and February of 2005 and more sampling was done upstream with mixed results. The University of Massachusetts is currently doing a more detailed investigation of this subbasin using microbial source tracking methods which hopefully will reveal the sources of contamination.

Asnebumskit Brook at Princeton Street annually has elevated fecal coliform counts beginning in May or June and lasting throughout the summer and much of the fall. Samples were collected at a number of locations between Princeton Street and Route 122A upstream in September of 2005, but fecal coliform counts were elevated at all sites and no source was determined. Multiple possibilities exist including roosting pigeons underneath the Route 122A bridge, a dog kennel adjacent to the brook, native wildlife, and inadequate septic systems. Staff will continue to investigate and attempt to determine a source.

Water quality in the tributaries has historically been unable to meet state standards. New standards proposed by the DEP will provide a more rational means of looking at current and past water quality data. Drinking water tributaries will be required to maintain a geometric mean of less than 206 *E. coli* per 100mL. Assuming that 100% of fecal coliform are *E. coli* (worst case), the standard was met at all fifty-four sampling stations during 2005 and all stations since 2002, with the highest geometric mean for 2005 recorded from Asnebumskit Brook (Table 10).

TABLE 10 (part one of two)

GEOMETRIC MEAN FECAL COLIFORM

STATION	2005	2005 (dry)	2004	2003	2002	1998
Asnebumskit (Mill)	30	16	27			28
Asnebumskit (Prin)	76	62	87			
Ball Brook	12	8	15			4
Beaman 2	30	15	66	75		
Beaman 3	47	25	69	136		
Beaman 3.5	42	24	134			
Boylston Brook	19	13	30	39	17	11
Chaffins (Malden)	24	12	22			36
Chaffins (Poor Farm)	30	20	23			
Chaffins (Unionville)	12	7	10			8
Chaffins (Wachusett)	30	18	26			
Cook Brook (Wyoming)	74	33	36	34	19	58
East Wachusett (140)	22	17	19			15
East Wachusett (31)	10	7	11			
East Wachusett (Bull)	12	9	13			
French Brook (70)	14	8	17	28	14	15
Gates Brook (1)	23	16	26	32	17	24
Gates Brook (2)	54	38	29	77	47	62
Gates Brook (3)	30	19	32	45	40	53
Gates Brook (4)	45	29	40	54	45	99
Gates Brook (6)	58	41	49	55	49	59
Gates Brook (9)	28	19	42	29	27	21
Hastings Cove Brook	14	11	12	20	12	7
Hog Hill Brook	19	10	14			
Houghton Brook	24	20	18			
Jordan Farm Brook	39	11	16		8	21
Justice Brook	8	8	9			2

TABLE 10 (part two of two)

GEOMETRIC MEAN FECAL COLIFORM

STATION	2005	2005 (dry)	2004	2003	2002	1998
Keyes (Gleason)	9	8	13			15
Keyes (Hobbs)	15	12	18			
Keyes (Onion)	8	7	9			
Malagasco Brook	26	17	26	57	23	27
Malden Brook	17	12	30	14	15	26
Muddy Brook	17	15	20	19	15	19
Oakdale Brook	38	23	49	40		
Quinapoxet River (CMills)	30	19	40	36	33	
Quinapoxet River (dam)	24	13	19	37		16
Quinapoxet River (Mill St)	12	8	11			4
Rocky Brook	19	13	12			8
Rocky (E Branch)	10	9	5		4	1
Scanlon Brook	15	11	13			3
Scarlett Brook	40	33	26			43
Scarlett (Rt12)	44	33	20			
Stillwater (62)	26	22	25			
Stillwater River (SB)	27	19	34	31	25	28
Swamp 15 Brook	28	17	26			36
Trout Brook	15	9	10			4
Warren Tannery Brook	19	11	19			
Waushacum (Conn)	23	20	12			
Waushacum (filter)	33	17	23			
Waushacum (Fairbanks)	30	25	25			
Waushacum (Pr)	23	16	14	20	19	27
Waushacum (WWP)	11	11	9			
West Boylston Brook	63	58	47	49	40	39
Wilder Brook	37	27	36			19

Twenty-one of the stations had a geometric mean of less than twenty fecal coliforms per 100mL in 2005, and over the period examined (1998, 2002-2005) more than forty percent of the stations had an annual geometric mean of less than twenty fecal coliforms per 100mL (Table 10). The key change is use of geometric mean (a measure of central tendency, like median values) rather than arithmetic mean. The geometric mean is especially useful when you have highly skewed data, like fecal coliform concentrations in tributaries.

Historical data were examined to detect any obvious long-term water quality trends. A more detailed assessment is underway which will review water quality data from 1998-2007 and compare it with data from the previous ten-year period. As described earlier, fecal coliform concentrations in 2005 were mostly comparable to those measured during 2004 and in previous years. Six stations (Gates 3, Hog Hill, Keyes at Gleason, Malden, Warren Tannery, and the Quinapoxet River at Canada Mills) did record their lowest ever annual median, and all three stations on Beaman Pond Brook continue to show significant improvement. Two stations (Cook and Gates 2) showed declining water quality and the former recorded its highest ever median coliform concentration, disturbing in light of the fact that many of the homes in the surrounding subbasin have been connected to the new municipal sewer. The remaining forty-three sampling stations all had median fecal coliform concentrations that were not unusually high or low and did not show any clear historical trends.

Geometric means were also used to assess historical data and possible trends. Most stations sampled from 1998 through 2005 were relatively unchanged during the period, including stations at French, Gates 1, Gates 2, Gates 6, Gates 9, Malagasco, Muddy, Stillwater, Quinapoxet, and Waushacum (Table 10). Malden Brook showed some improvement, although water quality during 2004 was poor. Boylston Brook experienced a decline in water quality over the period but rebounded in 2005. West Boylston Brook seemed to show a steady decline in water quality. Three stations did show significant improvement. Both Gates 3 and Gates 4 had geometric means that were considerably lower than that recorded during 1998, and both stations are located in areas that have had numerous homes recently connected to sewers. Cook Brook also showed a significant improvement and is also an area with many new sewer connections, but water quality inexplicably declined in 2005. The source of the contamination is under investigation.

3.2 NUTRIENTS

Samples for alkalinity, conductivity, nitrate-nitrogen, nitrite-nitrogen, ammonia, silica, total phosphorus, total suspended solids, UV-254, and total organic carbon were collected in March, April, June, July, and November from nine tributary stations and analyzed at the MWRA Deer Island Lab using methods with low detection limits. Monthly samples (except August) for the same parameters plus metals were collected from the Quinapoxet and Stillwater Rivers and sent to the MWRA as well. Samples for nitrate-nitrogen, nitrite-nitrogen, and ammonia were filtered in the field using a 1 micron glass fiber Acrodisc and then frozen; samples for total phosphorus were frozen without filtration. Samples for the other parameters were preserved as necessary according to standard methods. Flow measurements at these stations were determined each week using staff gages and USGS rating curves, or taken directly from continuous USGS recording devices. All data are included in an appendix to this report and are discussed in the following section.

Nitrate-nitrogen concentrations measured in the eight routine tributaries ranged from 0.017 mg/L NO_3-N to 2.78 mg/L NO_3-N (Table 11). Nitrate levels are usually highest in Gates and West Boylston Brooks and remain significantly elevated with respect to the other tributaries and the reservoir. This was again true in 2005, although concentrations in both brooks are declining. Elevated nitrate levels in Gates and West Boylston Brooks are likely due to the high number of improperly functioning septic systems and the density of residential and commercial development in these subbasins. The drop in nitrate-nitrogen concentration that is taking place is not unexpected; a majority of homes in the subbasin are now connected to the municipal sewer system. A similar decline in nitrate-nitrogen concentrations was not noted in the other tributaries, with mean values similar to those recorded in previous years.

TABLE 11

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

STATION	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	0.248	1.14	0.152	1.66	2.78	0.491	0.631	0.303
MIN	0.017	0.242	0.069	1.07	1.09	0.166	0.155	0.036
MEAN	0.103	0.596	0.097	1.50	1.95	0.386	0.270	0.163

Samples were collected as part of an ongoing study to evaluate the impacts of sewering on water quality in a small urbanized tributary (Cook Brook). Concentrations are usually higher in Cook Brook than in any of the routine tributaries sampled during the year, and this was true again in 2005. The Cook Brook subbasin has recently been sewered and improvements to water quality may be occuring. The maximum nitrate-nitrogen concentration recorded in 2005 was the lowest maximum in six years. Samples were also collected from two similar sized subbasins with different land uses for comparison purposes. Concentrations in Jordan Farm Brook (agriculture) and in Rocky Brook (undeveloped) remain significantly lower than in Cook Brook (dense residential) but were not lower than in previous years (Table 12).

TABLE 12

NITRATE-NITROGEN CONCENTRATIONS (mg/L)

STATION	COOK	COOK	COOK	COOK	COOK	COOK	Jordan Farm	Jordan Farm	Rocky (EBranch)	Rocky (EBranch)
YEAR	2000	2001	2002	2003	2004	2005	2004	2005	2004	2005
MAX	5.82	4.59	4.63	4.78	4.46	3.15	1.41	1.98	0.012	0.064
MIN	2.18	1.98	4.39	1.90	1.71	2.34	1.25	1.22	0.009	0.007

Nitrite-nitrogen was rarely detected and at very low concentrations, with a maximum recorded value of 0.016 mg/L measured in March at Jordan Farm Brook. Only six of sixty-seven samples and only five of the eleven tributaries contained detectable concentrations of nitrite-nitrogen (>0.005 mg/L) during 2005.

Ammonia was detected in all tributaries during the year with most concentrations similar but slightly higher than those seen in the previous two years (Table 13). An extremely high value was recorded from Jordan Farm Brook (0.953 mg/L) in March which was nearly ten times higher than any other measured value and more than one hundred times greater than the maximum value recorded from that station during the previous year. Data were collected five times during the year at most stations (eleven times from the Quinapoxet and Stillwater Rivers) to get a better overall picture of seasonal changes and to allow for the calculation of meaningful annual statistics. Samples will be collected six times in 2006 to help look for any long term trends.

TABLE 13

AMMONIA-NITROGEN CONCENTRATIONS (mg/L)

STATION	FRENCH	MALAG	MUDDY	GATES	W.BOYL	MALDEN	QUIN	STILL	COOK	J.FARM	ROCKY (EB)
MAX	0.097	0.085	0.104	0.038	0.085	0.033	0.042	0.029	0.084	0.953	0.006
MIN	0.034	0.015	0.016	0.006	0.006	0.011	0.010	<0.005	0.006	0.010	<0.005
MEAN	0.055	0.035	0.052	0.014	0.029	0.020	0.021	0.013	0.028	0.271	<0.005

Phosphorus is an important nutrient, and is the limiting factor controlling algal productivity in Wachusett Reservoir. EPA Water Quality Criteria recommend a concentration of no more than 0.05 mg/L total phosphorus in tributary streams in order to prevent accelerated eutrophication of receiving water bodies. Concentrations measured in the eight routine Wachusett tributaries during 2005 ranged from 0.008 mg/L to 0.160 mg/L total P (Table 14). Concentrations were higher in all of the smaller tributaries than they were in 2004, with greatly elevated maximum values noted at various times during the year. Concentrations in the two rivers were actually slightly lower than they were in 2004. Twelve of sixty-seven samples collected in 2005 exceeded the recommended maximum concentration.

TABLE 14

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

STATION	station	FRENCH	MALAGASCO	MUDDY	GATES	W.BOYLSTON	MALDEN	QUINAPOXET	STILLWATER
MAX	MAX	0.160	0.113	0.137	0.081	0.185	0.158	0.051	0.055
MIN	MIN	0.015	0.039	0.015	0.011	0.011	0.011	0.008	0.010
MEAN	MEAN	0.056	0.057	0.042	0.034	0.051	0.057	0.020	0.023

Data from Cook Brook in the Pinecroft neighborhood (Table 15) had appeared to indicate that water quality was improving as a result of the new sewers. Total phosphorus data were collected in 1998 prior to sewer construction, and a maximum value of 4.74 mg/L was recorded. Maximum values have not exceeded 0.2 mg/L since that time, and declined annually through 2003. The maximum value recorded in 2004 was twice as high as the previous year, however, and the maximum was even higher in 2005. Samples were collected monthly though 2001, only twice each in 2002, 2003, and 2004, and five times in 2005, so it is difficult to compare data and look for trends. Annual median values have been very consistent during the past eight years with the exception of 2004 when the annual median was twice that of all other years. A complete analysis of nutrient data including an assessment of the impacts of storm events is underway and will be included in the ten-year summary of water quality data to be published within the next few years.

Total phosphorus samples were also collected from two similar sized subbasins with different land uses for comparison purposes. Concentrations in Jordan Farm Brook (agriculture) and in Rocky Brook (undeveloped) were significantly lower than in Cook Brook (dense residential).

TABLE 15

TOTAL PHOSPHORUS CONCENTRATIONS (mg/L)

STATION	COOK	COOK	COOK	COOK	COOK	COOK	Jordan Farm	Jordan Farm	Rocky (EBranch)	Rocky (EBranch)
YEAR	2000	2001	2002	2003	2004	2005	2004	2005	2004	2005
MAX	0.095	0.053	0.031	0.033	0.081	0.101	0.043	0.277	0.015	0.038
MIN	0.008	0.012	0.021	0.009	0.031	0.016	0.016	0.032	0.011	<0.005
MEDIAN	0.020	0.024	0.026	0.021	0.056	0.024				
SAMPLES	11	10	2	2	2	5				

Silica concentrations ranged from a low of 3.63 mg/L in April (French Brook) to a high of 19.6 mg/L in March (West Boylston Brook). The annual mean concentration in the watershed during 2005 was 7.66 mg/L, very similar to the annual mean recorded for the previous three years. The annual mean concentration was highest in West Boylston Brook; the lowest annual mean concentrations were in French Brook, the Quinapoxet River, and the Stillwater River.

TABLE 16

SILICA CONCENTRATIONS (mg/L)

STATION	FRENCH	MALAG	MUDDY	GATES	W.BOYL	MALDEN	QUIN	STILL	COOK	J.FARM	ROCKY (EB)
MAX	7.48	10.80	8.78	10.30	19.60	10.50	9.23	9.12	10.50	10.90	11.60
MIN	3.63	4.26	4.60	6.70	6.57	5.11	4.16	4.81	7.64	6.02	5.93
MEAN	5.58	7.55	6.99	8.80	11.09	8.19	6.32	6.83	9.39	7.91	8.21

Total suspended solids are those particles suspended in a water sample retained by a filter of 2μm pore size. These particles can be naturally occurring or might be the result of human activities. Total suspended solids in Wachusett tributaries ranged from <5.0 mg/L to 93 mg/L, with fifty-one of sixty-seven samples containing less than the detection limit. High suspended solids were measured during March in West Boylston, Gates, and Jordan Farm Brook, and in November in Muddy and Malagasco Brooks.

Total organic carbon (TOC) and UV-254 measure organic constituents in water and are important as a way to predict precursors of harmful disinfection byproducts. TOC in the tributaries ranged from 1.61 to 19.1 mg/L, with an overall mean value of 5.43 mg/L. These values are similar to measurements done during 2003 and 2004. The highest readings were again recorded from Malagasco Brook and French Brook, and the lowest from Gates Brook and West Boylston Brook, although West Boylston Brook also had a single very high value in March. Measurements of UV-254 were comparable to TOC measurements as expected. Organic compounds such as tannins and humic substances absorb UV radiation and there is a correlation between UV absorption and organic carbon content. The highest UV-254 readings were also from Malagasco and French Brooks.

Concentrations of twenty-one metals were measured in monthly samples that were collected from the Stillwater and Quinapoxet Rivers. No antimony, beryllium, cadmium, nickel, selenium, silver, or thallium were detected in any samples, while arsenic, chromium, copper, lead, and mercury were present but at very low concentrations (less than 10 μg/L). Barium and zinc were present in slightly higher concentrations but never higher than 26 μg/L. Aluminum, calcium, iron, magnesium, manganese, potassium, and sodium were present at higher concentrations (Table 17) comparable to values recorded during the past three years.

TABLE 17

METALS CONCENTRATIONS (mg/L) – annual mean and range

STATION	Al	Ca	Fe	Mg	Mn	K	Na
QUINAPOXET	0.20	6.92	0.47	1.32	0.09	1.47	19.3
range	0.64 - 0.06	10.8 - 5.25	1.80 - 0.18	2.24 - 1.01	0.34 - 0.03	1.79 - 1.19	27.2 – 11.9
STILLWATER	0.12	6.17	0.38	1.14	0.08	1.28	16.9
range	0.26 - 0.02	16.7 - 2.90	1.05 - 0.11	2.95 - 0.64	0.27 - 0.03	2.73 - 0.84	31.5 - 10.4

3.3 SPECIFIC CONDUCTANCE

Fresh water systems almost always contain small to moderate amounts of mineral salts in solution. Specific conductance is a measure of the ability of water to carry an electric current, which is dependent on the concentration and availability of these ions. Elevated conductivity levels are indicative of contamination from stormwater or failing septic systems, or can be the result of watershed soil types.

Specific conductance was measured weekly at all stations with a low of 35 μmhos/cm in October at Rocky Brook (East Branch) and a high of 3060 μmhos/cm in September at East Wachusett (Route 31). This latter site had a number of high readings during low flow in the summer and fall, and continues to show the impacts of historic runoff from salt storage at the Princeton municipal yard. A reading of 1406 μmhos/cm during August at Boylston Brook was the result of a storm event that also increased fecal coliform concentrations to 1700 fcu/100mL. The highest values were seen during the summer and fall and were likely the result of low flow. In previous years the highest values were noted during the winter and spring and were related to snow and ice storms, salt applications, and elevated runoff.

Annual median ranged from a low of 52 μmhos/cm (Justice Brook) to a high of 1007 μmhos/cm (Gates 6 at Lombard Avenue). Annual values in most tributaries were similar to the previous year, with most differences less than ten percent. Sixteen tributaries had their highest annual median values ever, although a number of them were only slightly higher than the previous year and conductivities in many of them were relatively low. French Brook, Houghton Brook, and the Stillwater River had elevated specific conductance measurements likely due to reduced flow caused by active beaver populations. More disturbing was the sharp rise in Scarlett Brook and the continued increase to new maximums in five of six stations on Gates Brook. The expected improvements following a large number of new sewer connections has not yet been observed.

Criteria were proposed by the DWM during the mid 1990s relating specific conductance and fecal coliform levels to the likelihood of contamination from failing septic systems. A simple statistical analysis was used to develop a ranking system for tributaries, using percent exceedence of specific criteria. Tributaries with more than fifty percent of the samples exceeding the Class A Standard for fecal coliform of twenty colonies per 100mL are potentially impacted by septic systems. Impacts are considered minor if less than eighty percent of samples exceed a specific conductance standard of 120 μmhos/cm, moderate if greater than eighty percent of samples exceed the 120 μmhos/cm standard, and severe if more than twenty percent of samples exceed a standard of 360 μmhos/cm. These criteria appear to give a fairly good indication of whether or not a sampling location is impacted by failing septic systems rather than by an alternative source of contamination, although annual flow conditions need to be considered. It is important to note that changes in sampling equipment have led to overall increases in specific conductance throughout the watershed and these criteria may need to be updated. The use of fifty percent exceedence as an indicator of potential impact by septic systems should also be used with caution, since rain events and periods of reduced flow have a significant impact on fecal coliform concentrations and the timing of sampling during the year could easily change overall results. Conductivity appears to be directly related to stream flow, with "dry" years (low flows) concentrating contaminants during the warm months and elevating mean annual conductivity. Years with less precipitation and lower tributary flow result in higher overall conductivity measurements and appear to increase the number of streams severely impacted. For this reason multiple years should be used in assessing these criteria.

An assessment of specific conductance and fecal coliform data from 2005 using the criteria described above suggests that seventeen of fifty-four stations (31%) were likely contaminated by improperly functioning septic systems. All three stations on Beaman Pond Brook, four of six stations on Gates Brook, and stations on Cook, Oakdale, Scarlet, Swamp 15, and West Boylston Brooks were considered severely impaired. Problems along Cook, Oakdale, Gates, Scarlett, and West Boylston Brook have been well documented, and sewers have recently been constructed specifically to deal with this issue. Beaman Pond Brook has had problems believed to be related to horses rather than septic systems. Fecal coliform concentrations have declined and elevated conductivity in this instance may be the result of road salt rather than septic impacts, although it is also possible that some septic system problems are also present nearby.

Swamp 15 Brook has a watershed with limited residential development but a considerable amount of agriculture and potential wildlife habitat. Although the criteria seem to suggest that the contamination is from septic systems, agriculture and wildlife are more likely sources. The cause of elevated specific conductance is unknown.

Asnebumskit Brook at Princeton Street and Scarlett Brook at Route 12 showed moderate impacts from septic systems. These two tributaries have exhibited poor water quality in the past although the source has never been determined. The sampling station on the Quinapoxet River at Canada Mills showed moderate impacts from septic systems, while stations at the upper end of the river (Mill Street) and at the mouth (dam) were not impacted. The Stillwater River continues to exhibit minor to moderate impacts from septic systems, possibly the result of upstream contributions from its tributaries, although no obvious problems were identified during field work for the Stillwater River Environmental Quality Assessment Report.

A multi-year examination (1998 through 2005) of this assessment showed conditions initially improving and then stabilizing in the watershed. Nearly fifty percent of the stations assessed in 1998 were deemed likely contaminated by faulty septic systems. This declined to thirty-eight percent in 1999, thirty-three percent in 2000, and thirty percent in 2001 and in 2002. Poor conditions in 2003, with more than fifty percent of the stations likely contaminated by septic systems, were due to the addition of several problem stations to the routine weekly sampling run and the dropping of two locations with good water quality. A large number of tributaries were assessed in 2004 and 2005 to provide a better overall picture of water quality in the watershed, and the percentage of stations likely contaminated by septic systems declined to thirty percent.

3.4 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity, or the measure of a solution’s acidity or alkalinity, is expressed as pH on a scale ranging from 0 to 14. Underlying geologic formations, biological processes, and human contaminants impact the pH of a water body. In this region most streams and lakes tend to be relatively acidic (pH less than 7) due to granite bedrock and the impact of acid precipitation originating from the Midwest.

No measurements of pH have been done in the tributaries for a number of years. More than a decade of routine sampling in the tributaries had shown very little variation either seasonally or over time. Historic low values in some tributaries may have been caused by impacts of runoff from acid precipitation, while all other recorded values are considered to be representative of normal background conditions.

3.5 *GIARDIA / CRYPTOSPORIDIUM*

Giardia and *Cryptosporidium* samples were not collected by Environmental Quality staff during 2005 and no additional sampling is planned for the future. Data have been collected from a variety of locations in previous years, but no clear seasonal trends were determined and presence or absence appears to be related more to precipitation, flow conditions, and presence of wildlife rather than season.

4.0 RESULTS OF RESERVOIR MONITORING PROGRAM

4.1 BACTERIA

Samples were collected Monday through Friday by MWRA staff from an internal tap until early August, and then weekly from the same location for the remainder of 2005. The new John J. Carroll Water Treatment Plant at Walnut Hill in Marlborough came on line in August and official compliance samples were collected five times per week at that location for the remainder of the year. EPA's fecal coliform criteria for drinking water require that at least ninety percent of all source water samples contain less than 20 colonies per 100mL. One hundred percent of the 167 samples collected at the Cosgrove Intake and the 100 samples collected at Walnut Hill contained less than the standard, with a maximum value of 14 colonies per 100mL recorded on December 20th. This is the first year that all samples have been in compliance with the standard. DCR has put considerable effort into developing and implementing a rigorous bird harassment program, and the results in 2005 were outstanding.

Bacterial transect samples were collected from twenty-three surface stations across the reservoir to document the relationship between seasonal bacteria variations and visiting populations of gulls, ducks, geese, and other waterfowl. Data were also used to judge the effectiveness of bird harassment activities. Sample locations were illustrated previously on Figure 2. Samples were collected monthly in January, May, June, August, and September, twice monthly in October and November, and three times in December. All fecal coliform transect data are included in Table 18 on the following page.

Samples collected in January 2005 reflected normal winter conditions prior to the reservoir freezing over. The harassment program had successfully moved birds away from the north end of the reservoir near the intake and roosting birds (and high fecal coliform levels) were concentrated to the south. The reservoir froze over on January 19th and remained ice covered until early April.

No stations anywhere in the reservoir contained more than fifteen fecal coliform colonies per 100mL during May, June, August, and September except for a single high sample near mid reservoir in August. Fecal coliform concentrations in the southern part of the reservoir increased in October, but only a single station north of the narrows (the 'bird-free' zone) contained more than twenty fecal coliform colonies per 100mL. Elevated concentrations were noted north of the narrows in November, but harassment activities were increased and concentrations declined. The number of birds and the number of bacteria remained high in the southern part of the reservoir throughout December, and by the end of the month there were elevated fecal coliform concentrations throughout the reservoir, including the north end. Samples collected at and near the intake contained less than twenty fecal coliform colonies per 100mL, but samples collected at mid reservoir and in Prescott Cove contained 22-55 fecal coliform colonies per 100mL. Harassment activities intensified again and fecal coliform concentrations at the intake never exceeded the water quality standard.

TABLE 18

FECAL COLIFORM TRANSECT DATA (colonies/mL)
Wachusett Reservoir - 2005

SITE	5-Jan	17-May	29-Jun	18-Aug	14-Sep	12-Oct	26-Oct	9-Nov	23-Nov	8-Dec	14-Dec	28-Dec
A-3	0	3	1	0	3	0	**10**	1	**10**	2	5	**12**
B-2	1	**14**	0	0	1	0	4	0	6	3	3	**17**
B-3	3	**11**	0	1	0	0	1	1	**12**	1	4	**11**
C-1	4	6	0	0	1	1	3	3	10	5	6	**17**
C-3	2	7	0	0	0	1	3	3	**25**	4	2	**10**
C-5	0	0	1	0	2	1	1	0	5	3	6	**10**
D-1	8	1	0	1	5	1	4	8	**11**	7	6	**18**
D-2	7	**11**	0	0	1	1	7	**17**	**12**	8	5	**55**
D-4	1	4	0	0	4	2	1	4	7	5	4	**16**
E-2	3	**15**	0	**76**	1	3	6	**32**	**25**	**10**	**15**	**37**
E-4	1	3	0	2	2	**13**	4	3	8	8	**41**	**36**
F-2	4	1	0	1	1	3	7	**11**	**23**	**11**	**13**	**22**
F-3	3	3	0	1	3	4	5	4	**24**	6	8	**44**
F-4	4	1	0	0	1	**21**	0	**12**	**17**	**18**	**11**	**39**
G-2	6	0	0	0	3	**12**	7	5	**11**	8	**70**	**28**
H-2	**20**	0	0	3	1	2	7	2	**10**	**26**	**30**	**36**
I-2	**14**	0	0	0	0	4	**10**	5	**10**	12	**33**	**41**
J-2	**17**	0	2	1	0	6	**14**	1	2	**79**	**24**	**19**
J-3	**61**	0	0	0	0	**11**	**11**	4	**25**	8	**120**	**72**
J-4	**>200**	2	0	0	**15**	**12**	5	**44**	**37**	**115**	**37**	**33**
K-2	**109**	0	0	1	1	**30**	5	**13**	**65**	**90**	**180**	**30**
M-1	**35**	0	2	5	1	**35**	**15**	6	**16**	**39**	**74**	**17**
N-1	**37**	0	1	0	1	**23**	4	9	**12**	**59**	**73**	7

4.2 WATER COLUMN CHARACTERISTICS

4.2.1 FIELD PROCEDURE

DCR staff routinely measure water column profiles in the Wachusett Reservoir for the following hydrographic parameters: temperature, dissolved oxygen, percent oxygen saturation, specific conductance, and hydrogen ion activity (pH). Profiles are measured weekly at Basin North/Station 3417 in conjunction with plankton monitoring (see Section 4.4) and quarterly at the other key monitoring stations (Basin South/Station 3412 and Thomas Basin; see Figure 1) weather and ice conditions permitting.

The thermally stratified water column of summer is characterized by a layer of warm, less dense water occupying the top of the water column ("epilimnion"), a middle stratum characterized by a thermal gradient ("metalimnion"), and a stratum of cold, dense water at the bottom ("hypolimnion"). Profile measurement during the period of thermal stratification is important for many reasons including the following: (1) to monitor phytoplankton growth conditions and detect "blooms" of potential taste and odor causing organisms associated with discrete strata of the water column (see section on phytoplankton), (2) to track the progress of the Quabbin "interflow" through the Wachusett basin during periods of water transfer (see below), and (3) to monitor water quality within each stratum and determine appropriate depths for vertically stratified nutrient sampling. Profiles are measured at one meter intervals, except during periods of isothermy and mixing (generally November through March) when intervals of two or three meters are adequate to characterize the water column.

Water column profiles are measured with a "Reporter" or "H20" multiprobe and "Surveyor 3" water quality logging system manufactured by Hydrolab Corporation (now a component of the Hach Company located in Loveland, Colorado). These instruments are routinely charged and calibrated during the field season. At the conclusion of field work, data recorded by the logging system is downloaded to a PC as an Excel spreadsheet.

Basin North/3417 has been selected for graphically depicting seasonal changes in the water column profile of Wachusett Reservoir because it is representative of the deepest portion of the basin and it is not influenced by turbulence from local water inputs or withdrawals that could disrupt profile characteristics. Profiles measured in Thomas Basin and at Cosgrove Intake (Station 3409) are influenced by inflow from the Quabbin Aqueduct and withdrawal at the Cosgrove Intake respectively.

4.2.2 THE QUABBIN "INTERFLOW" IN WACHUSETT RESERVOIR

The transfer of water from Quabbin to Wachusett Reservoir via the Quabbin Aqueduct has a profound influence on the water budget, profile characteristics, and hydrodynamics of the Wachusett Reservoir. During the years 1995 through 2005, the amount of water transferred annually from Quabbin to Wachusett ranged from a volume equivalent to 44 percent of the Wachusett basin up to 94 percent. The period of peak transfer rates generally occurs from June through November. However, at any time of the year, approximately half of the water in the Wachusett basin is derived from Quabbin Reservoir.

The peak transfer period overlaps the period of thermal stratification in Wachusett and Quabbin Reservoirs. Water entering the Quabbin Aqueduct at Shaft 12 is withdrawn from depths of 13 to 23 meters in Quabbin Reservoir. These depths are within the hypolimnion of Quabbin Reservoir where water temperatures range from only 9 to 13 degrees C in the period June through October. This deep withdrawal from Quabbin is colder and denser relative to epilimnetic waters in Wachusett Reservoir. However, due to a slight gain in heat from mixing as it passes through Quinapoxet Basin and Thomas Basin, the transfer water is not as cold and dense as the hypolimnion of Wachusett. Therefore, Quabbin water transferred during the period of thermal stratification flows conformably into the metalimnion of Wachusett where water temperatures and densities coincide.

The term interflow describes this metalimnetic flow path for the Quabbin transfer that generally forms between depths of 7 to 15 meters in the Wachusett water column. The interflow penetrates through the main basin of Wachusett Reservoir (from the Route 12 Bridge to Cosgrove Intake) in about 3 to 4 weeks depending on the timing and intensity of transfer from Quabbin. The interflow essentially connects Quabbin inflow to Cosgrove Intake in a "short circuit" undergoing minimal mixing with ambient Wachusett Reservoir water.

In 2005, a sustained transfer was initiated on May 20th and was nearly continuous through October 11th, but with interruptions June 4th and 5th, August 31st, and September 15th through 18th. Subsequent to the termination of sustained transfer on October 11th, transfer was resumed briefly from November 23rd through the 29th. A slight deflection in the conductivity profile to lower values was detected at Basin North/3417 on June 16th (see Specific Conductance section below) indicating complete interflow penetration through the main basin to Cosgrove Intake about a week later in an interval estimated at 35 days from transfer initiation.

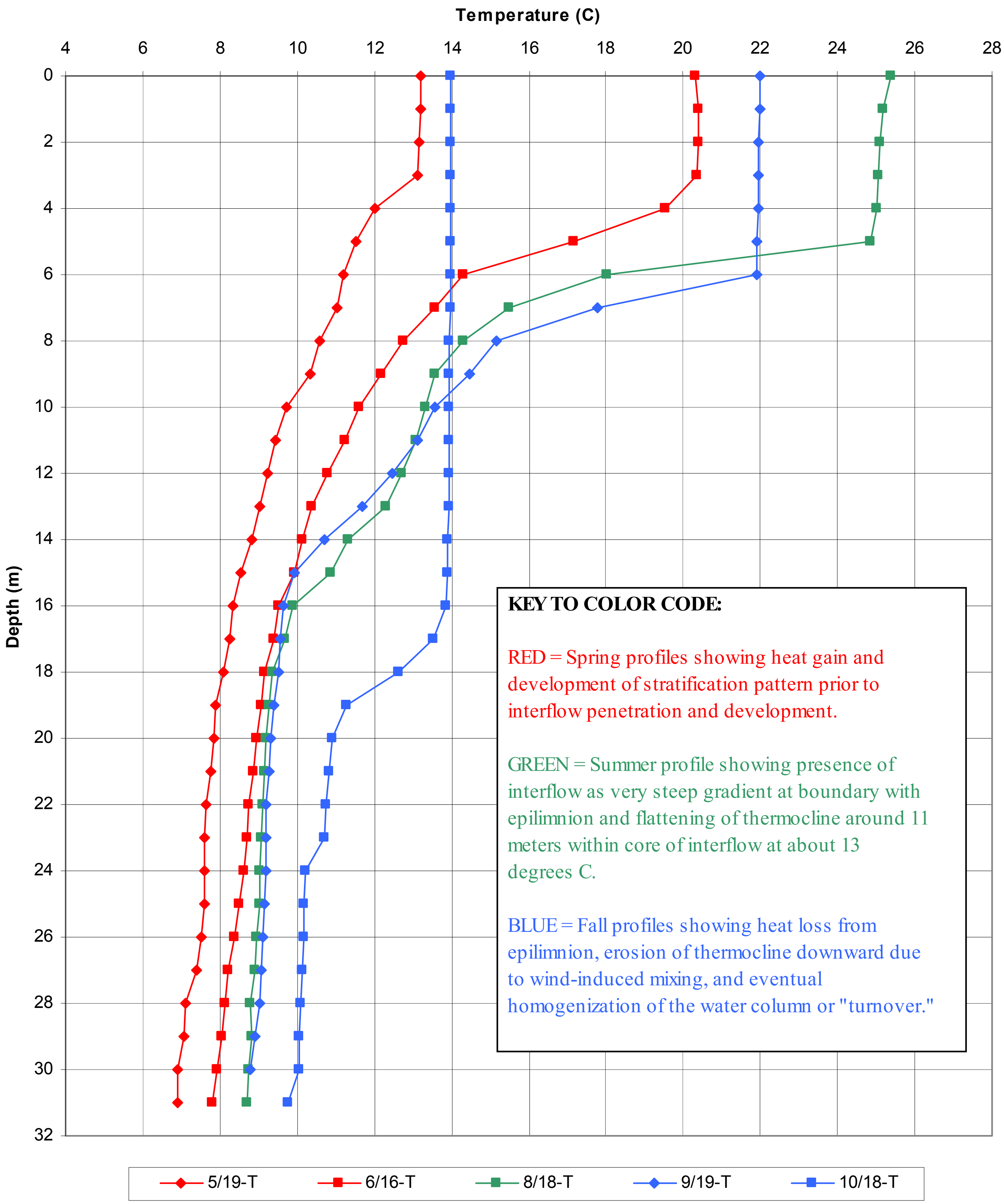
By late-August, the interflow stratum had developed into a configuration slightly more expansive than typical with a thickness of eleven meters forming between 5 and 16 meters deep. At the conclusion of 2005, the transfer volume totaled 37,559 million gallons (142 million cubic meters), equivalent to 57 percent of the capacity of Wachusett Reservoir. The influence of the 2005 Quabbin interflow on profile characteristics in Wachusett Reservoir is discussed in the sections that follow.

4.2.3 TEMPERATURE

Typical of most deep lakes and reservoirs in the temperate region, Wachusett Reservoir becomes thermally stratified in summer. The development of thermal stratification due to solar radiation and atmospheric warming in spring and summer and the subsequent loss of heat leading to fall turnover at Basin North/3417 is depicted in Figure 3.

An early stage of thermal stratification was evident on the May 19th measurement date when a difference of approximately 6º C existed between the top and bottom of the water column. The top of the water column continued to gain heat and a fairly uniform gradient from 20.3º C at the surface extending down to around 10º C at a depth of 14 meters is evident on June 16th.

Figure 3
2005 Temperature Profiles at Basin North/Station 3417



The establishment of the interflow from Quabbin (see Interflow section above) can been seen in the profile measured on August 18th. A very steep thermal gradient exists between depths of five and seven meters in which the temperature dropped almost 10º C. This steep gradient in temperature and density caused by the interflow stabilized the position of the metalimnion between depths of approximately 5 and 16 meters.

The presence of the Quabbin interflow was also evident in the temperature profiles as a pronounced flattening or plateau in the thermocline between 9 and 13 meters where the temperature centers around 13 º C. This plateau represents the “core” of the interflow stratum that undergoes minimal mixing with ambient Wachusett water.

Highest temperatures in the epilimnion were recorded in August at 25º C while temperatures in the hypolimnion remained at about 9º C throughout the summer. The September profile shows that the system began to lose heat as radiation intensities diminished and air temperatures cooled.

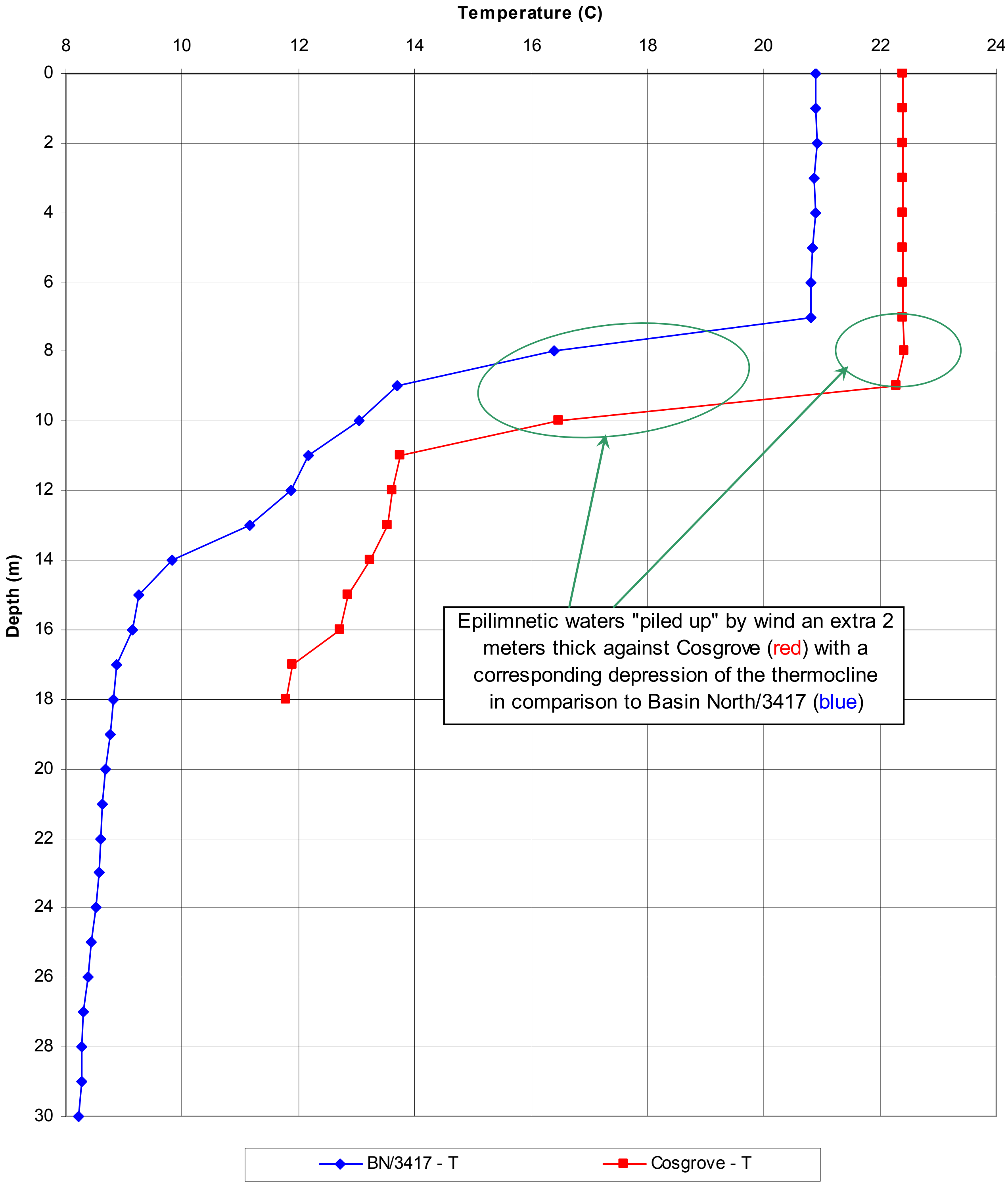
The profile measured on October 18th shows that heat losses and wind energy had caused the water column to be mixed down to a depth of 16 meters thus homogenizing the epilimnion and the metalimnetic Quabbin interflow. A difference of about 4º C existed between the top and bottom of the water column at this time (Figure 3). Soon after the October 18th measurement date, wind energy dispersed the remnant stratification pattern and mixed the entire water column, in an event known as fall “turnover”. The water column was shown to be essentially isothermal at around 10.9º C in a profile recorded on November 3rd.

An opportunity for characterizing the formation and magnitude of an internal seiche in Wachusett Reservoir was exploited during field work on September 12th when a strong west wind had been blowing steadily all morning. Profiles were recorded at Basin North/3417 as usual and then off the catwalk at the rear of Cosgrove Intake immediately after returning to the boat dock. A comparison of these profiles shows the epilimnion “piled up” an additional two meters thick against Cosgrove with a corresponding depression of the thermocline (Figure 4).

This is the typical “set up” phase of an internal seiche when a strong, steady wind causes epilimnetic water to be piled up on the lee shore (Cosgrove Intake on the eastern shore) and metalimnetic water is forced to windward as the thermocline is deflected downward. Upon cessation of wind stress, the deformed water strata surge back toward the equilibrium position as counter-currents, but overshoots due to momentum. The epilimnion and metalimnion oscillate opposite to each another resulting in rocking of the thermocline across the basin A uninodal internal standing wave on the epi-/metalimnetic boundary is the type most commonly set in motion (Wetzel, 1983).

Details of the period of oscillation and the extent to which this internal standing wave is propagated across the reservoir basin are unknown as profile measurements were not resumed later after cessation of wind released the potential energy of strata deformation. However, it is likely that the constriction at the Narrows functions to dampen or even reflect the oscillation as an antinode which, according to the simplest model (Wetzel, 1983), would give a period of oscillation of about seven hours. It is important to note that following similar episodes of wind, the position of phytoplankton aggregated within the thermocline at a depth of 8 meters in main basin could potentially range between depths of 6 to 10 meters at Cosgrove Intake due to an internal seiche.

Figure 4
Temperature Profiles at Basin North/Station 3417 and Cosgrove Intake
Recorded on September 12, 2005 During Strong West Wind



4.2.4 DISSOLVED OXYGEN

Measurement of dissolved oxygen profiles throughout most of the year generally show values ranging from 60 to 100 percent saturation for ambient water temperatures. Saturation values in the epilimnion remained around 90 percent or more throughout the year, whereas saturation values in the metalimnion and hypolimnion declined progressively from May through October (Figure 5).

Minor peaks in dissolved oxygen saturation values were observed in June (at a depth of 5 meters) and again in August (at a depth of 6 meters), but these were not associated with dense aggregations of phytoplankton. This is in contrast to 2004 when a remarkable metalimnetic bloom of *Chrysosphaerella* was evident in profile measurements as a spike in dissolved oxygen saturation values up to 109.6 percent that persisted at a depth of 7.5 meters from early July through mid-August (see 2004 annual report).

During the period of thermal stratification, demand for oxygen in the hypolimnion reduced oxygen concentrations to between 45 and 55 percent saturation before fall turnover in late October replenished oxygen throughout the water column. Reductions in oxygen concentration are also evident in most of the metalimnion during the stratification period, but these are mainly indicative of oxygen demand within the Quabbin interflow and the Quabbin Reservoir rather than processes within Wachusett Reservoir. Relatively low saturation values measured near the bottom of the water column indicate slightly higher rates of oxygen demand by microbial decomposition processes occurring at the sediment-water interface.

The profile measured on October 18th, shows homogenization of the water column down to 16 meters with the attendant replenishment of oxygen to around 80 percent saturation throughout the mixed volume. By early November, wind energy dispersed the remnant stratification pattern mixing and exposing the entire basin volume to the atmosphere thereby replenishing dissolved oxygen concentrations to around 80 percent saturation at all depths.

4.2.5 SPECIFIC CONDUCTANCE

Specific conductance (“conductivity”) profiles in Wachusett Reservoir reflect the interplay between native water contributed from the Wachusett watershed and water transferred from Quabbin. The Quinapoxet and Stillwater Rivers are the two main tributaries to Wachusett Reservoir and are estimated to account for approximately 75 percent of annual inflow from the reservoir watershed. Measurements of conductivity in these rivers generally range between 60 and 240 uS/cm with an average value between 125 and 150 uS/cm. In contrast, the average conductivity value of Quabbin water is approximately 40 uS/cm.

During periods of isothermy and mixing (November through March), conductivity values throughout the main Wachusett basin typically range from 75 to 145 uS/cm depending on the amount of water received from Quabbin. During the summer stratification period the Quabbin interflow is conspicuous in profile measurements as a metalimnetic stratum of low conductivity. Figure 6 depicts conductivity profiles measured at Basin North/3417 from May through October.

Figure 5
2005 Dissolved Oxygen (% Saturation) Profiles at Basin North/Station 3417

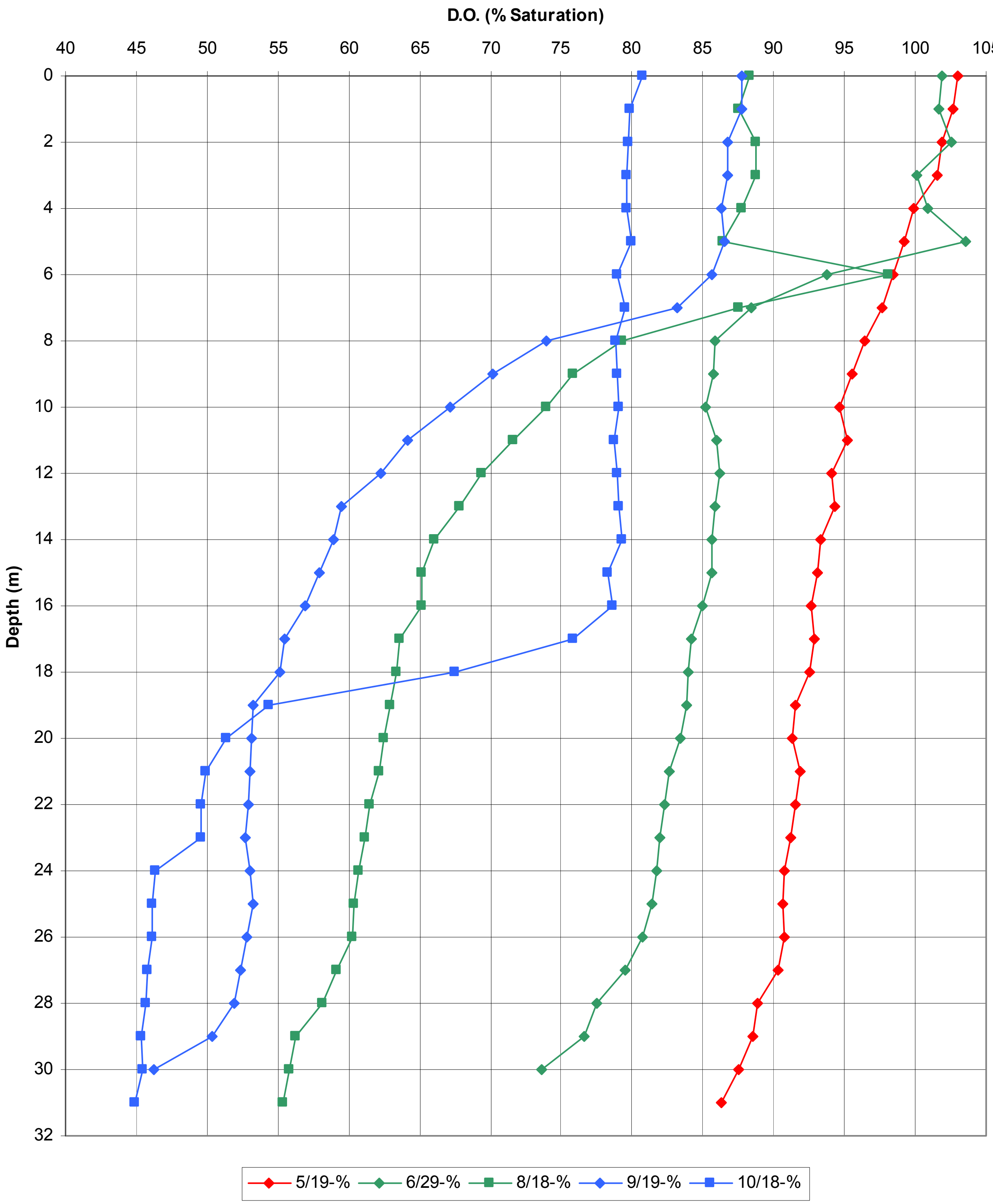
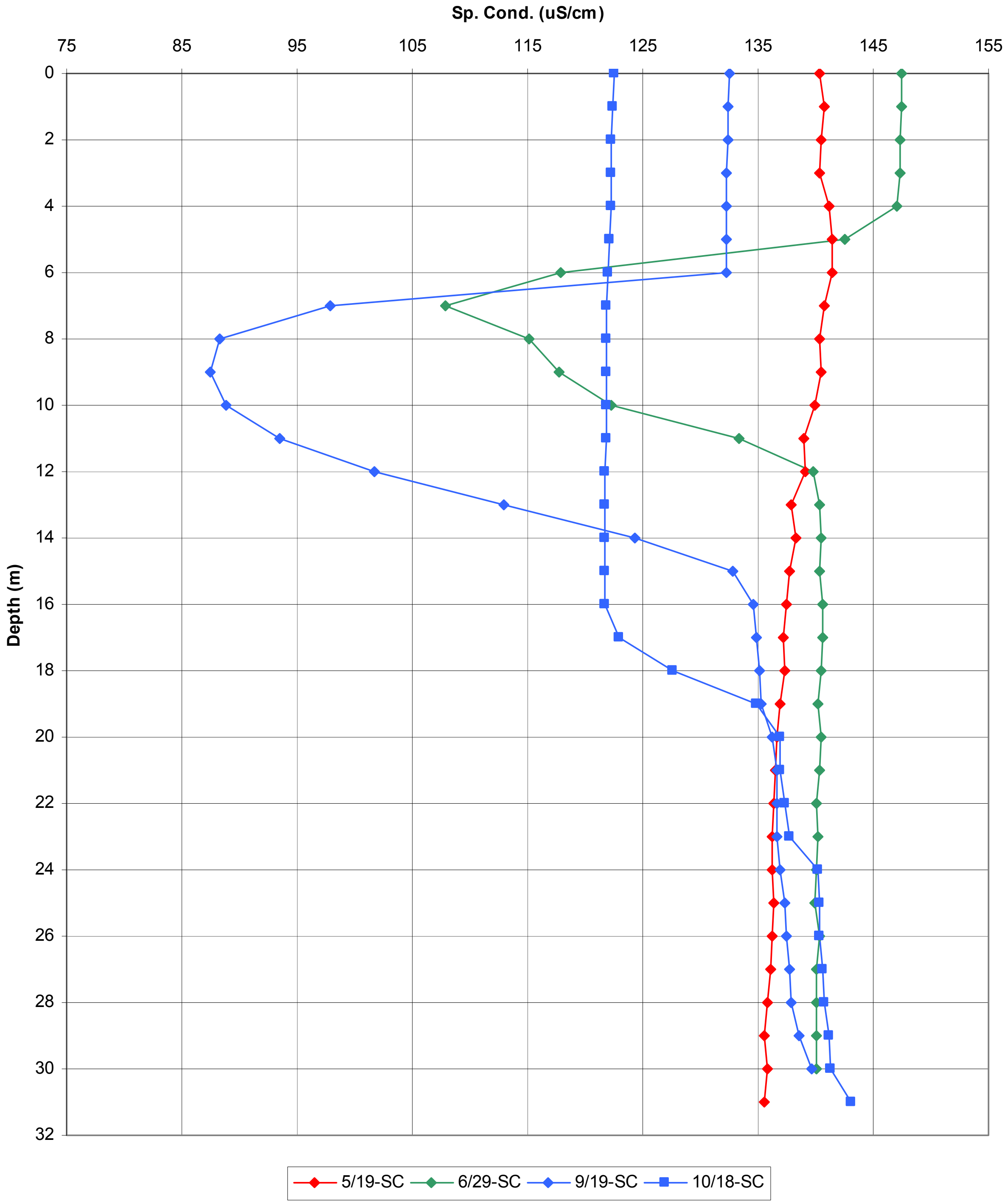


Figure 6
2005 Specific Conductance Profiles at Basin North/Station 3417



On May 19th, before the Quabbin transfer had penetrated to Basin North/3417, conductivity values ranged between 135 and 142 uS/cm throughout the water column. The profile recorded on June 29th shows the development of the interflow stratum as a "trough" in the conductivity profile between depths of around 5 and 12 meters. This trough intensifies (extends to lower conductivity values) over the period of transfer as water in the interior of the interflow undergoes less mixing with ambient reservoir water at the boundaries of the interflow stratum. By September 19th, a minimum interflow conductivity value of 87.5 uS/cm was observed at a depth of 9 meters at Basin North/3417.

Profiles measured on October 18th show that heat losses and wind energy had caused the water column to be mixed down to a depth of 16 meters thus homogenizing the epilimnion and the metalimnetic interflow stratum. The conductivity of this mixed portion of the water column was about 122 uS/cm. By early November, wind energy had dispersed the remnant stratification pattern causing conductivity in the entire water column to register around 123 uS/cm.

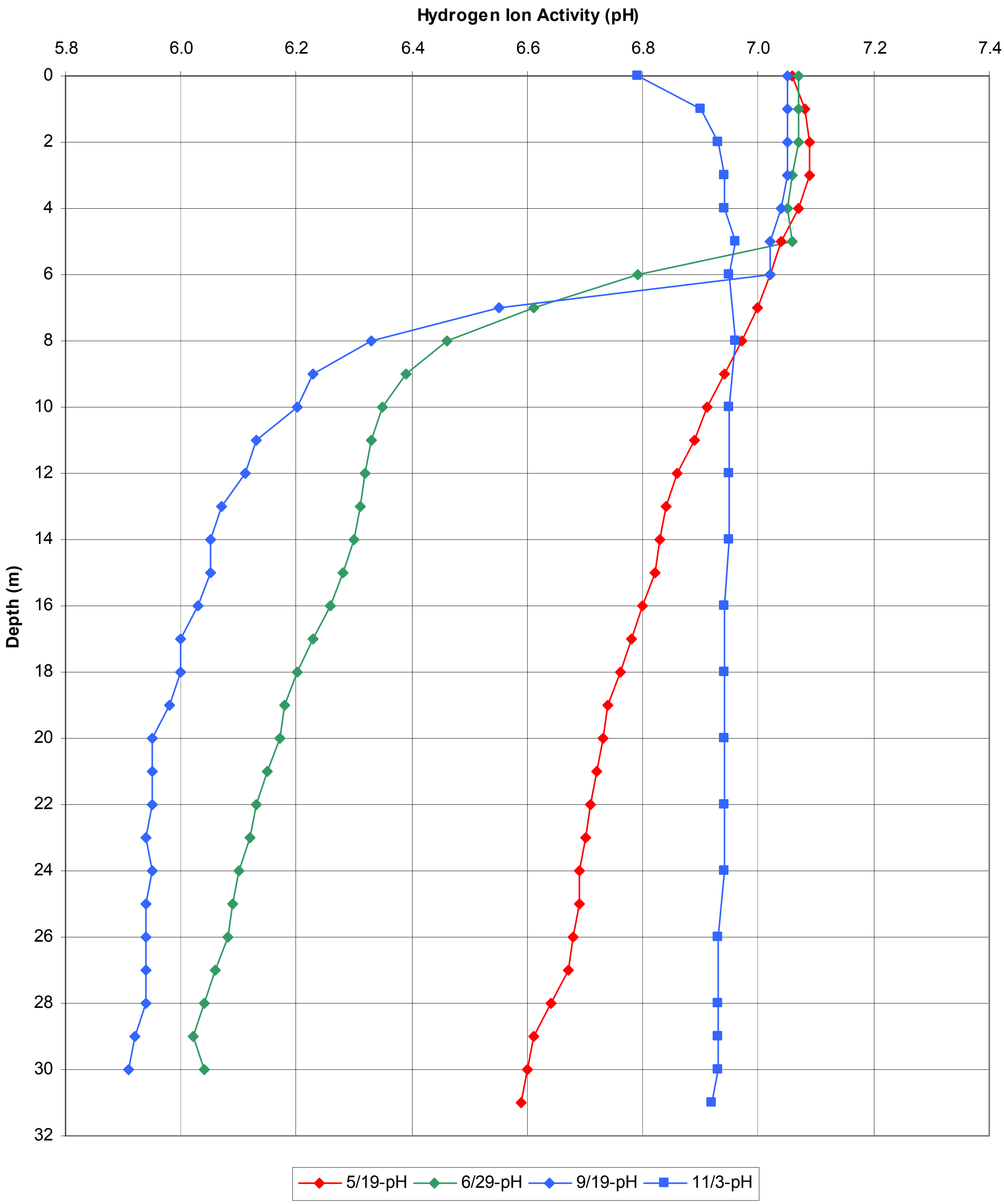
4.2.6 HYDROGEN ION ACTIVITY (pH)

Hydrogen ion activity (pH) in Wachusett Reservoir is determined ultimately by the exchange of inorganic carbon between the atmosphere and water (the carbon dioxide-bicarbonate-carbonate "buffering system"). Specific patterns of pH distribution vertically in the water column and seasonally over the year are mainly determined by the opposing processes of photosynthesis and respiration. Generally, pH values in Wachusett Reservoir range from around neutral (pH=7) to slightly acidic (pH=6). Figure 7 depicts pH profiles measured at Basin North/3417 from May through November.

Epilimnetic values of pH generally remained near neutral throughout the year. Values slightly greater than neutral result from photosynthetic activity by phytoplankton inhabiting this most productive stratum of water. Photosynthesis results in the uptake of carbon dioxide dissolved in the water and this removal of carbon dioxide tends to increase pH in the epilimnion where photosynthetic activity is greatest. Metalimnetic values of pH ranged from 6.2 to 6.8 during most of the stratification period, but these are mainly indicative of the Quabbin interflow and the Quabbin Reservoir rather than processes occurring within Wachusett Reservoir.

In contrast to the utilization of carbon dioxide by photosynthetic organisms, microbial decomposition of organic matter produces carbon dioxide. In the hypolimnion, where microbial respiration is the dominant process, the production of carbon dioxide tends to decrease pH. Hypolimnetic pH declined during the period of thermal stratification reaching a value around 5.9 by September 19th However, mixing associated with "turnover" in late October restored equilibrium conditions with the atmosphere resulting in pH values of about 6.9 uniformly throughout the water column as recorded on November 3rd.

Figure 7
2005 Hydrogen Ion Activity (pH) Profiles at Basin North/Station 3417



4.3 NUTRIENTS

4.3.1 FIELD PROCEDURE

Sampling for measurement of nutrient concentrations in Wachusett Reservoir has been conducted quarterly since the conclusion of the program of monthly sampling conducted from October 1998 to September 1999. Quarterly sampling was conducted at the onset of thermal stratification (May), in the middle of the stratification period (July), near the end of the stratification period (October), and during a winter period of mixis before ice cover (December). Samples were collected at three of the main monitoring stations used in the 1998-99 year of study (Basin North/Station 3417, Basin South/Station 3412, and Thomas Basin; see Figure 1).

Samples were collected in the epilimnion, metalimnion, and hypolimnion during the period of thermal stratification and near the top, middle, and bottom of the water column during mixis. Water column profiles of temperature, dissolved oxygen, and other parameters measured with a multiprobe were evaluated in the field to determine depths for metalimnetic samples.

Quarterly sampling continued to be performed in collaboration with MWRA staff at the Deer Island Central Laboratory who provided sample containers and where all grab samples were sent for analysis. Sampling protocol, chain-of-custody documentation, and sample delivery were similar to those established in the 1998-99 year of study. Details of sampling protocol are provided in the comprehensive report on Wachusett Reservoir nutrient and plankton dynamics (Worden and Pistrang, 2003).

Modifications to the quarterly sampling program have consisted only of a lower minimum detection limit for total Kjeldahl-nitrogen (reduced to 0.05 mg/L from previous limits of 0.2 and 0.6 mg/L) and the addition of UV254 absorbance (in 2000) and dissolved silica (in 2004) among the parameters to be measured. Measurement of UV absorbance at a wavelength of approximately 254 nanometers serves as is a relative assay of the concentrations of organic compounds dissolved in the water. Samples to be analyzed for dissolved silica are field filtered (0.45µm membrane) and these measurements complement conventional silica analyses that have been conducted since the beginning of the sampling program.

4.3.2 RESULTS OF NUTRIENT ANALYSES

The nutrient database for Wachusett Reservoir established in the 1998-99 year of monthly sampling and subsequent quarterly sampling through 2004 is used as a basis for interpreting data generated in 2005. Most results from quarterly nutrient sampling in 2005 document concentrations and intensities that register almost entirely within historical ranges (Table 19; see complete quarterly database in Appendix).

The significant exception to this observation is evident among the parameters measured in Thomas Basin and, in particular, the elevated values of silica, total phosphorus, and UV254 absorbance recorded in samples collected on October 18th. These elevated values are linked to the exceptional amount of rainfall received in early October and associated high rates of discharge from the Quinapoxet and Stillwater Rivers.

Table 19 - Wachusett Reservoir Nutrient Concentrations:
Comparison of Ranges from 1998-04 Database[1] to Results from 2005 Quarterly Sampling [2]

Sampling Station [3]	Ammonia (NH3; ug/L)		Nitrate (NO3; ug/L)		Silica (SIO2; mg/L)		Total Phosphorus (ug/L)		UV254 (Absorbance/cm)	
	1998-04	Quarterly'05	1998-04	Quarterly'05	1998-04	Quarterly'05	1998-04	Quarterly'05	2000-04	Quarterly'05
Basin North/3417 (E)	<5 - 12	<5 - 13	<5 - 159	20 - 152	0.59 - 3.27	1.85 - 3.34	<5 - 13	<5 - 17	0.032 - 0.072	0.050 - 0.081
Basin North/3417 (M)	<5 - 36	12 - 24	<5 - 164	39 - 154	0.77 - 3.31	2.21 - 3.65	<5 - 17	<5 - 20	0.032 - 0.079	0.047 - 0.084
Basin North/3417 (H)	<5 - 41	5 - 22	48 - 202	101 - 225	1.27 - 3.92	3.19 - 4.11	<5 - 14	<5 - 17	0.032 - 0.072	0.065 - 0.080
Basin South/3412 (E)	<5 - 14	<5 - 14	<5 - 172	22 - 155	0.56 - 3.84	1.81 - 3.76	<5 - 17	<5 - 20	0.031 - 0.085	0.057 - 0.095
Basin South/3412 (M)	<5 - 39	13 - 17	11 - 184	51 - 161	0.95 - 4.03	2.36 - 3.72	<5 - 22	<5 - 21	0.032 - 0.089	0.050 - 0.094
Basin South/3412 (H)	<5 - 44	<5 - 18	49 - 224	111 - 206	1.64 - 4.13	3.35 - 4.04	<5 - 37	<5 - 18	0.036 - 0.091	0.073 - 0.092
Thomas Basin (E)	<5 - 18	<5 - 7	<5 - 201	20 - 144	0.62 - 5.00	1.92 - 5.11	<5 - 23	10 - 27	0.026 - 0.153	0.066 - 0.305
Thomas Basin (M)	<5 - 27	<5 - 15	<5 - 205	25 - 147	0.88 - 4.94	2.00 - 5.20	<5 - 22	6 - 24	0.026 - 0.155	0.054 - 0.301
Thomas Basin (H)	<5 - 57	8 - 19	<5 - 236	18 - 144	0.92 - 4.99	1.95 - 5.35	<5 - 24	5 - 23	0.027 - 0.200	0.036 - 0.289

Notes: (1) 1998-04 database composed of 1998-99 year of monthly sampling and subsequent quarterly sampling through December 2004, except for measurement of UV254 initiated in 2000 quarterly sampling
(2) 2005 quarterly sampling conducted May, August, October, and December
(3) Water column locations are as follow: E = epilimnion/surface, M = metalimnion/middle, H = hypolimnion/bottom

A remarkable total of 12.3 inches of rain was recorded at Wachusett in a 9-day period between October 7th and 15th. The Quinapoxet and Stillwater Rivers comprise approximately 75% of the total Wachusett watershed area and they discharge and mix in Thomas Basin before entering the main reservoir basin. Vigorous loading of silica, total phosphorus, and dissolved organic compounds from these major tributaries resulted from the heavy rain events and these parameters were measured at record levels in Thomas Basin a few days later.

Coincidentally, the annual transfer from Quabbin which functions to dilute and ameliorate the influence of these rivers on reservoir water quality had been terminated on October 11th to ensure adequate storage capacity for the tremendous volumes of runoff generated by the heavy rains. In summary, the elevated values measured in October samples from Thomas Basin reflect very high loading rates from the Quinapoxet and Stillwater Rivers operating in the absence of water transferred from Quabbin.

The patterns of nutrient distribution in 2005 quarterly samples correspond closely to those documented in the comprehensive report on Wachusett Reservoir nutrient and plankton dynamics (Worden and Pistrang, 2003). These patterns consist most importantly of the following: (1) prominent seasonal and vertical variations with low epilimnetic concentrations in summer resulting from phytoplankton uptake and higher concentrations accumulating in the hypolimnion due to microbial decomposition of sedimenting organic matter, (2) interannual fluctuations in nutrient concentrations and parameter intensities occurring across the main basin as a result of the divergent influences of the Quabbin transfer and the Wachusett watershed with temporary lateral gradients becoming pronounced for nitrate, silica, UV254, and conductivity, either increasing or decreasing downgradient of Thomas Basin depending on the dominant influence.

4.4 PHYTOPLANKTON

4.4.1 FIELD PROCEDURES

Sampling from a boat at Basin North/Station 3417 during the late-April through early-November thermal stratification period has been a key element of phytoplankton monitoring since 2003 when new staff assignments and procedures were implemented. Boat sampling replaced the previous method of collecting grabs at various depths from the catwalk at the rear of Cosgrove Intake. Basin North/Station 3417 is representative of the deepest portion of the basin and it is not influenced by seiche effects or turbulence from water withdrawals which can destabilize stratification boundaries and obscure associated phytoplankton growth patterns at Cosgrove Intake. However, samples collected at Cosgrove are adequately representative of the main basin during the late-November through early-April period of mixis when the water column is homogenous, so sampling is conducted from the catwalk during this period ice conditions permitting.

Sampling frequency is generally weekly in early spring, fall, and winter increasing to twice a week (usually Monday and Thursday) during the period from May through September when episodes of rapid population growth ("blooms") by problematic "taste and odor" organisms generally occur. Samples are usually collected at two depths which varies slightly between periods of mixis and stratification. During periods of mixis, samples are collected as follows: (1) near the top of the water column at a depth of three meters and (2) at a depth of eight meters corresponding to the upper intake depth at Cosgrove. During the annual stratification period samples are collected as follows: (1) near the middle of the epilimnion at a depth of three meters and (2) near the bottom of the epilimnion at a depth of six meters, and (3) within strata pinpointed by distinctive profile measurements (see below). Additionally, surface samples are collected in June and July when a bloom of the cyanophyte *Anabaena* frequently accumulates at the surface. Samples are collected using a Van Dorn Bottle and returned to the laboratory for concentration and microscopic analysis (details given below in next section).

In addition to grab sampling, routine phytoplankton monitoring during the stratification period also includes measurement of hydrographic parameters such as temperature, dissolved oxygen, hydrogen ion activity (pH), and specific conductance with a Hydrolab multiprobe (see section on water column profile measurements). These parameters are measured at one meter intervals as the multiprobe is lowered from the surface to record a profile of the entire water column. Secchi transparency is also recorded as an approximate measure of the amount of particulates, mostly plankton, suspended in the water column.

During the stratification period, when spikes in dissolved oxygen concentrations in profile measurements (a "positive heterograde curve") indicate photosynthetic activity associated with a phytoplankton bloom within a specific stratum of the water column, an additional grab sample is collected at that depth to identify and quantify the bloom organism. Motile colonial chrysophytes ("golden-brown algae") such as *Chrysosphaerella*, *Dinobryon*, and *Synura* are generally responsible for subsurface blooms in Wachusett Reservoir and the "bloom stratum" that they prefer is generally between six and eight meters coincident with the steep temperature gradient at the interface between the epilimnion and the metalimnetic interflow.

Productivity by phytoplankton during the stratification period is almost exclusively restricted to the epilimnion and its boundary with the metalimnetic interflow (motile chrysophytes generally aggregate within upper margin of the metalimnion no deeper than eight meters). The absence of significant photosynthetic activity below the epilimnion/interflow boundary has been documented consistently since 1987 by multiprobe measurements of water column profiles. Steadily declining concentrations of dissolved oxygen below this boundary over the weeks of the stratification period indicate that microbial decomposition of sedimenting organic matter is the dominant biological activity. It is likely that the steep temperature and density gradients at this boundary prohibit inoculation and/or dispersion of photosynthetic organisms into the metalimnetic interflow.

4.4.2 LABORATORY CONCENTRATION AND MICROSCOPIC ANALYSIS OF PLANKTON

Prompt acquisition of information on phytoplankton densities is critical for agency decision-making on the need for algaecide applications to avoid taste and odor problems. The method of sand filtration for concentration of phytoplankton samples has long been in use by both MWRA and DWSP because it enables relatively rapid analysis of samples while subjecting organisms to minimal damage or distortion. The specific method used is documented in Standard Methods Twelfth Edition (1965, pages 669-671; photocopies kindly provided by Warren Zepp of MWRA). In brief, the method entails gravity filtration of sample water placed in a funnel through a layer of fine sand followed by washing and gentle shaking of the sand with waste filtrate water in a beaker to detach organisms from the sand grains, and lastly, prompt decanting of the concentrated sample after the sand has been allowed to settle. A portion of the concentrated sample is then analyzed microscopically using quantitative techniques as presented below.

Phytoplankton taxa in concentrated samples are enumerated using a Sedgewick-Rafter (S-R) Cell which enables phytoplankton densities to be quantified. Each concentrated sample is mixed to homogenize the sample and then 1 ml of the sample is withdrawn with a pipette and placed into the S-R Cell. Initial inspection of phytoplankton within the S-R Cell is accomplished with a stereozoom dissecting microscope capable of magnification from 7 to 45 times. Use of this instrument to scan the entire S-R Cell is important to detect colonies of certain motile taxa present at low densities such as *Synura* and/or colonies floating against the underside of the coverslip such as *Anabaena*. Analysis of surface samples collected in June and July is limited to scanning unless *Anabaena* is detected at densities amenable to enumeration using a compound microscope (see below).

Scanning of the entire S-R cell enables colonial "taste and odor" organisms to be detected and quantified at very low densities. Colonies observed in the S-R Cell using the stereozoom dissecting microscope are quantified by counting the number of colonies and then measuring their average diameter using a compound microscope (see below). This information, along with the known concentration factor arising from sand filtration, is used to calculate and express densities of colonial "taste and odor" organisms as Areal Standard Units (see below).

After the scanning procedure described above, microscopic analysis of phytoplankton samples is next performed with a compound microscope capable of magnification from 40 to 1,000 times and using phase-contrast illumination. Approximately 15 minutes are allowed for the phytoplankton to settle to the bottom of the S-R Cell before enumeration. Phytoplankton are enumerated in a total of 10 fields described by an ocular micrometer. At 200X magnification, the ocular field measures 0.3136 square millimeters in area (previously calibrated with a stage micrometer) and the fields are selected for viewing at approximately 0.5 cm intervals across the length of the S-R Cell.

Phytoplankton densities are expressed as Areal Standard Units (ASU; equivalent to 400 square microns) per milliliter. The area of each specimen viewed in each counting field is estimated using the ocular micrometer (the ocular field is divided into a 10 by 10 grid, each square in the grid having an area of 3,136 square microns or 7.84 ASU at 200X magnification). In the case of taxa which form gelatinous envelopes or are enclosed in a colonial mucilage, such as *Microcystis*, the area of the envelope is included in the estimate for that specimen. The areal extent of certain colonial taxa, such as the diatoms *Asterionella* and *Tabellaria*, is estimated by measuring the dimensions of one cell and multiplying by the number of cells in the colony. Cell fragments or structures lacking protoplasm, including lorica of *Dinobryon*, diatom frustules, and thecae of dinoflagellates, are not included in the count.

4.4.3 MONITORING RESULTS

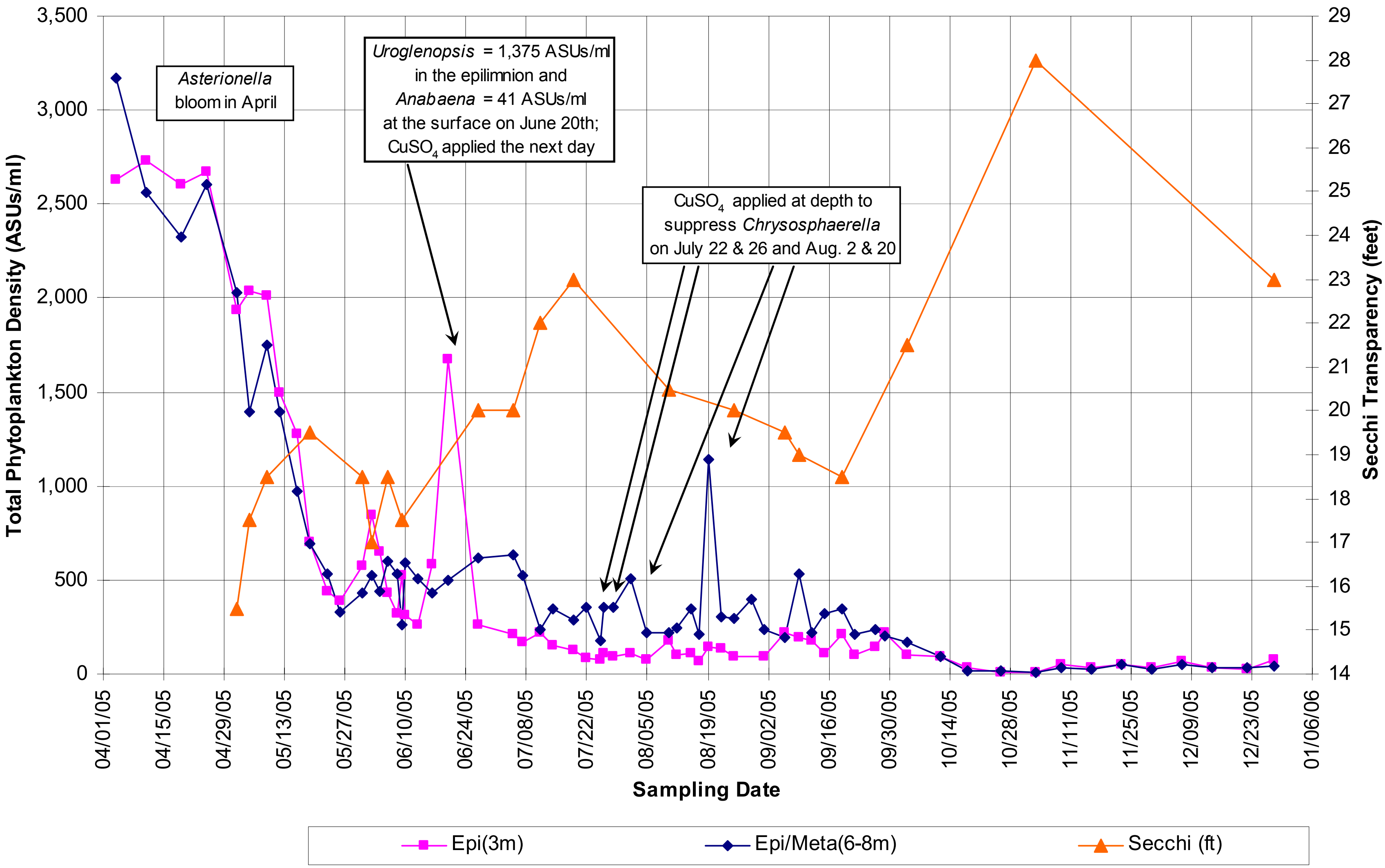
The highest densities of 2005 were observed at the outset of annual monitoring efforts with the diatom *Asterionella* measured at densities ranging from 2,300 to 3,200 ASUs/ml immediately upon loss of ice cover in early April (Figure 8). A spring bloom of diatoms is a common feature of seasonal phytoplankton dynamics in Wachusett Reservoir (see review given in Worden and Pistrang, 2003). *Asterionella* densities declined gradually through the end of May.

The subsidence of *Asterionella* was followed closely in June by the appearance of the chrysophyte *Uroglenopsis* and the cyanophyte *Anabaena* in the epilimnion. Initially, densities of these two organisms remained low, but by June 20th densities had increased to problematic levels (*Uroglenopsis* at 1,375 ASUs/ml in the epilimnion and *Anabaena* at 41 ASUs/ml in a typical surface accumulation) prompting MWRA to conduct a copper sulfate application the following day.

Relatively minor episodes of phytoplankton growth occurred in July and August when the chrysophyte *Chrysosphaerella* appeared at depth. In 2004, a remarkable bloom of this organism aggregated at a depth of 7.5 meters and persisted for seven weeks accompanied by a pronounced spike in dissolved oxygen saturation values (see 2004 annual report). Minor peaks in dissolved oxygen saturation values were observed in some 2005 profiles, but these were located higher in the water column and were transitory. Most importantly, samples collected at the depths where these minor profile spikes were observed did not contain dense aggregations of phytoplankton. However, the presence of *Chrysosphaerella* at varying densities prompted several applications of copper sulfate by MWRA in order to avoid complaints of unpleasant taste and odor from water consumers as experienced in 2004. *Chrysosphaerella* was last observed among the plankton on September 1st.

Densities of all phytoplankton declined to low values by mid-October (less than 50 ASUs/ml) and generally remained at these low levels for the remainder of the year. The lack of a resurgence in diatom densities at the end of the year is atypical for Wachusett phytoplankton. Generally, a secondary peak in diatom densities occurs in fall in response to the breakdown of thermal stratification and mixing (“turnover”) which redistributes nutrients accumulated in the hypolimnion throughout the water column.

Figure 8
2005 Plankton Monitoring at Wachusett Reservoir



4.5 MACROPHYTES

4.5.1 THE THREAT OF EURASIAN WATER-MILFOIL

The Wachusett Reservoir system is a major component of the drinking water supply for greater Boston. In August of 2001, a pioneering colony of Eurasian Water-milfoil (*Myriophyllum spicatum;* referred to subsequently as "milfoil") was observed for the first time in Upper Thomas Basin, a small basin in the upper reaches of the reservoir system. Milfoil is an exotic, invasive species of macrophyte known to aggressively displace native vegetation and grow to nuisance densities with associated impairments to water quality. Prior to 2001, this plant was restricted to the uppermost component of the reservoir system, Stillwater Basin, where its distribution has been monitored since 1999.

The expansion of milfoil into Upper Thomas Basin represents a significant increase in the risk of a potentially rapid and overwhelming dispersal of this plant into the main reservoir basin. The water quality implications of such an event are serious and include increases in water color, turbidity, phytoplankton growth, and trihalomethane (THM) precursors. These increases result from the function of this plant and macrophytes in general as nutrient "pumps," extracting nutrients from sediment and releasing them to the water column, mostly as dissolved and particulate organic matter.

This function is especially intense with milfoil due to its characteristically rapid and prolific growth habit. Nutrient release occurs during most life cycle stages, but especially during senescence and death. Milfoil also releases nutrients and organic matter during canopy formation (lower leaves and branches are sloughed as upper stems grow horizontally along the surface) and when undergoing a propagation process known as autofragmentation. Autofragments are stem segments with adventitious roots at the nodes that float upon abscission and are the plant's most important mode of reproduction and dispersal. Autofragments of milfoil eventually sink to the bottom and are capable of colonizing littoral zone areas having only minimal deposits of organic sediment.

4.5.2 WACHUSETT RESERVOIR MILFOIL CONTROL PROGRAM

The 2001 expansion of milfoil into Upper Thomas Basin prompted DCR to design a milfoil control program which was implemented in 2002 and, in collaboration with MWRA, has continued to the present. Descriptions of milfoil control efforts in previous years are provided in their annual reports.

Milfoil control efforts in 2005 consisted of a continuation of the primary control technique of hand-harvesting as well as maintenance of the benthic barriers installed at the northern end of Upper Thomas Basin in 2002. The benthic barrier installation consists of a total of 72 panels of barrier material, each measuring 1,200 square feet (24' by 50'). These panels had an accumulation of sediment on top of them measuring up to a few centimeters in thickness which needed to be removed to preclude colonization by rooted aquatic plants. Some of the panels in the shallowest portion of the basin were designated for removal as a first step in restoring littoral zone habitat to its natural state now that the milfoil infestation in this portion of Upper Thomas Basin has been suppressed. Maintenance of the benthic barriers and hand-harvesting was conducted by Aquatic Control Technology (ACT) of Sutton, MA.

Additionally, MWRA commissioned a dredging feasibility assessment of Stillwater Basin which was conducted by Lycott Environmental, Inc. of Southbridge, MA. The primary focus of this study was assess the feasibility for sediment and plant removal in this basin by dredging or other mechanical means. Key components of this study included sediment characterization, a macrophyte survey, mapping, cost analysis, permitting evaluation, and impact assessment. Details of the 2005 milfoil control program are summarized below.

Hand-Harvesting of Eurasian Water-milfoil and Maintenance of Benthic Barrier Installation: Summary of ACT Efforts in 2005

- Removal of six panels of benthic barrier closest to shore and testing of barrier cleaning vacuum technique conducted on June 6th and 7th
- Preliminary GPS survey of Upper Thomas Basin and Thomas Basin proper conducted on June 17th
- Hand-harvesting in Upper Thomas Basin and Thomas Basin proper conducted from July 13th through July 18th (total of 4 working days)
- Vacuum cleaning of benthic barrier in Upper Thomas Basin conducted from July 19th through August 4th (sediment discharged in boomed containment area located adjacent to shore over substrates newly exposed by removal of six barrier panels)
- Hand-harvesting conducted from August 23rd and August 26th in Thomas Basin proper, "Powerline Cove" in the main basin (total of 21 specimens removed), and Upper Thomas Basin (total of 3 working days)
- Total diver-hours expended = 97 (compared to 135.5 hours in 2004, 93.25 hours in 2003, and 496.5 hours in 2002)
- Estimate of total milfoil plants removed = 4,847 (compared to 7,424 plants in 2004, 3,251 plants in 2003, and an estimated 75,000 - 100,000 plants removed in 2002)
- Similar to last year, the alien Fanwort (*Cabomba caroliniana*) is increasing in abundance in Upper Thomas Basin and is removed along with milfoil (total removed in 2005 = 860)
- Post-harvesting GPS survey of Upper Thomas Basin conducted on September 7th documents effective control of milfoil along shoreline, but significant regrowth on central "plateau" area (also routine scouting by DCR finds no milfoil in main basin)

Dredging Feasibility Assessment of Stillwater Basin: Highlights of the 2005 Final Report Prepared by Lycott Environmental, Inc.

- Section 6.0 of report: "Dredging … would be a difficult and expensive undertaking, including a detailed and lengthy permitting process." (involves NHESP, filing of an ENF and EIR with MEPA, DEP Section 401 Water Quality Certification, and USACOE Section 404 Clean Water Act Individual Permit)
- Time frame and cost estimated for permitting process ranges from 2-10 years at $200K
- Dredging would require construction of a 10,000 sq. foot stone staging area for heavy trucks on the western shoreline at an estimated cost of $60K
- Total cost estimate of dredging project ranges from $2.6 to $4.2 million
- Sections 6.0 and 6.3 of report: "it is more than likely that the macrophyte growth will continue to thrive after the dredging project ... re-growth may occur after two to three growing seasons."

In addition to the activities of consultants summarized above, DCR staff deployed floating fragment barriers (purchased in 2002) at strategic "bottleneck" locations to restrict the movement of milfoil autofragments into downgradient portions of the reservoir system. These locations are where floating fragment barriers were initially deployed in 2002 and consist of the railroad bridge between Stillwater Basin and Upper Thomas Basin and the Beaman Street Bridge between Upper Thomas Basin and Thomas Basin proper. In 2005, floating fragment barriers were deployed on April 26th.

One final activity related to the milfoil control program was the scouting of potential sources of the alien species Eurasian Water-milfoil and Fanwort within the Stillwater River watershed by DCR staff on September 8th. This effort focused on Paradise Pond (Princeton), Bartlett Pond (Leominster), and Stuart Pond (Sterling) and consisted of visual observations from a canoe. However, neither Eurasian Water-milfoil or Fanwort were observed in any of these three ponds.

Macrophyte Flora of Ponds of the Stillwater River Watershed (1)

Scientific Name	Common Name	Paradise Pond (2) (Princeton)	Bartlett Pond (3) (Leominster)	Stuart Pond (4) (Sterling)
Brasenia schreberi	Water Shield	X	X	X
Eleocharis sp.	Spike-rush	X		
Eriocaulon sp.	Pipewort	X		
Myriophyllum heterophyllum	Variable Water-milfoil	X		X
Myriophyllum humile (?)	Water-milfoil	X		
Najas flexilis	Naiad	X		
Nuphar variegata	Yellow Water-lily	X	X	X
Nymphaea odorata	White Water-lily	X	X	X
Potamogeton sp.	Pondweed	X	X	X
Utricularia purpurea	Purple Bladderwort	X	X	X
Utricularia radiata	Bladderwort	X		

Notes:
(1) Based on cursory visual observations conducted from a canoe on September 8, 2005
(2) Paradise Pond is uniformly shallow and the basin is carpeted with vegetation throughout; surface coverage by floating leaves ~30%
(3) Bartlett Pond has a central deep area beyond the photosynthetic limit of macrophytes; surface coverage by floating leaves ~50%
(4) Stuart Pond is very shallow and ~90% covered with floating leaves having only a narrow band of open water parallel to the eastern shore

4.5.3 PLANS FOR MILFOIL CONTROL EFFORTS IN 2006

The invasive nature of milfoil necessitates a long-term commitment to annual control efforts in the upper reaches of the Wachusett Reservoir system if its dispersal into the main basin is to be prevented. To meet this challenge, DCR and MWRA are working collaboratively to design and implement future control programs. Next year, during the 2006 growing season, plans call for a resumption of intensive hand-harvesting in Upper Thomas Basin. Early efforts will focus on harvesting plants in areas known to support regrowth of milfoil and the few specimens not removed last season. Dive crews will conduct hand-harvesting at intervals throughout the summer to suppress regrowth that sometimes occurs subsequent to initial harvesting efforts. Associated with hand-harvesting efforts, DCR staff will continue routine scouting for milfoil throughout the reservoir system to identify and target any pioneering specimens found in new locations. Also, DCR staff will redeploy the floating fragment barriers at their strategic "bottleneck" locations as done in previous years.

5.0 SUMMARY OF SITE INVESTIGATIONS

A total of ninety-nine new sites were investigated during 2005. A majority of the issues at these locations were related to residential or commercial development and resulted in problems with sedimentation and erosion, encroachment, or potential contamination. Construction projects included single family homes, subdivisions, a large apartment complex, commercial expansion, parking lots, additions, and sheds. Other problems addressed during 2005 included spills of hazardous materials, road reconstruction and bridge replacements, wetland alteration, sewer and septic problems, forestry operations, dam inspections, stormwater runoff, and manure storage.

Problems at eighty of the sites were addressed during 2005 and are now considered resolved. Three sites are currently on watch status. Work at these sites is being monitored and additional activities are necessary in some cases, but the OWM is confident that successful resolution of these issues will occur.

Sixteen sites originally investigated during 2005 remain active. Three involve wetland disturbances and DCR staff are working with local conservation commissions towards resolution. There are two roadways issues currently under review, a bridge repair over South Wachusett Brook and the construction and maintenance of stormwater management basins near Gate 25. There are three outstanding septic system repairs, along with two investigations of potential hazardous materials releases. The remaining issues are related to residential or commercial construction, ranging from subdivisions to the addition of an in-law apartment. There are also a number of additional locations from previous years that remain active as well, along with thirteen investigations initiated during the first few months of 2006.

A large number of existing issues were addressed during 2005. Many of these simply required follow-up communication and documentation, while others needed additional investigation or actions. A total of 782 files currently exist; 625 issues have been resolved and only forty-four files remain active. All other files are on watch status (forty-nine) or have not yet had their status determined.

6.0 SAMPLING PLAN FOR 2006

The Wachusett watershed sampling program for 2006 will once again include special studies, enforcement actions, incident response, and routine sampling and analysis. The routine sampling program will separate out the effects of storm events on tributary water quality from standard dry weather water quality data using detailed precipitation data from several stations in or near the watershed. The program was designed to protect public health, identify current and potential threats to water quality, and further our understanding of the reservoir and its tributaries.

Fecal coliform and conductivity will be measured weekly at fifty-four stations on thirty tributaries during dry weather. This is the third year of the expanded sampling program that collects data from a greater number of stations to be able to address issues that have been identified in previous water quality summaries and Environmental Quality Assessment reports. Quarterly nutrient samples will again be collected from nine tributary stations with available flow data. Separate wet weather sampling of eight major tributaries will be done to help quantify bacterial loading to the reservoir from storm events. Tributary sampling will take place immediately following rain events (first flush) and then the eight stations will be resampled after 24 and 48 hours to see how long elevated fecal coliform concentrations persist after a storm. Precipitation amounts and stream flows will all be carefully documented and compared to bacteria numbers to attempt to further refine our understanding of the causes of elevated fecal coliform levels in Wachusett tributaries. Further attempts will be made to relate seasonal effects on water quality responses to storm events.

Monthly temperature, dissolved oxygen, pH, and conductivity profiles will be taken at three reservoir stations (3417-Basin North, 3412-Basin South, and Thomas Basin) during ice-free periods using a Hydrolab H20 Sonde Unit and a Surveyor III data logger. More frequent profiles will be collected when necessary to document changing conditions in the reservoir. Plankton samples will be collected weekly or biweekly at multiple depths from the Cosgrove Intake or mid reservoir station 3417, and quarterly from Thomas Basin and mid reservoir station 3412. Samples for nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, total phosphorus, and both total and dissolved silica will be collected quarterly from 3417, 3412, and Thomas Basin. Fecal coliform bacteria samples will no longer be collected at the Cosgrove Intake by DCR. MWRA staff will continue to collect regulatory samples once per week from an internal tap and five days per week from the new water treatment plant in Marlborough.

The movement of water and contaminants through the reservoir, especially during times when water is being transferred to Wachusett Reservoir from Quabbin Reservoir, remains the focus of significant interest. Sampling of the reservoir surface will continue on a regular basis. Monthly, biweekly, or weekly bacterial transect sampling will be done during ice-free periods to help further understand the effect of water movement on fecal coliform levels throughout the reservoir. A consultant study of reservoir hydrodynamics should begin in 2006 to help improve our understanding of this important issue.

Sampling of the Pinecroft area drainage basin (Cook Brook) will continue as part of the routine weekly sampling program in order to evaluate the impacts of sewering on water quality in a small urbanized tributary to the Wachusett Reservoir. Results from 2005 were not encouraging, but the source of increased fecal coliform concentrations was not clear. A multidisciplinary team approach will be implemented in 2006 to help determine the source of the contamination and to propose remediation measures. Samples will also be collected from two similar sized drainage areas with different land uses for comparative purposes. Additional areas in West Boylston and Holden that have recently been sewered will also be examined to see if improvements can be detected, and historical data will be analyzed to help detect any possible positive trends.

Additional sampling will be done during 2006 to support the Worcester Basin Environmental Quality Assessment (in progress). Samples will also be collected as needed when water quality conditions change and problems are noted, and to help locate sources of contamination. Both West Boylston Brook and Asnebumskit Brook will be the subject of an intensive investigation to attempt to locate a persistent seasonal fecal coliform problem. A similar study of Malagasco Brook eliminated a number of potential sources from consideration and a final solution may be close at hand. Samples will also be collected to support any potential enforcement actions required by other OWM staff.

7.0 REFERENCES CITED:

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